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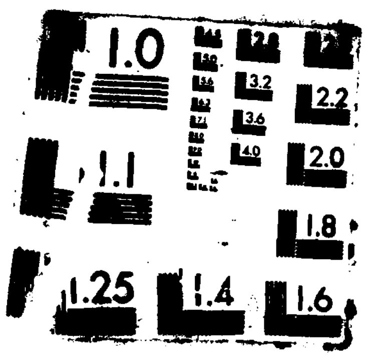
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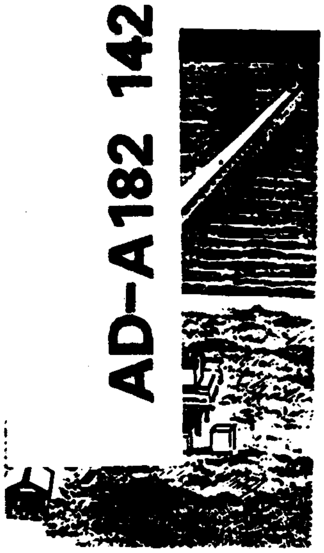

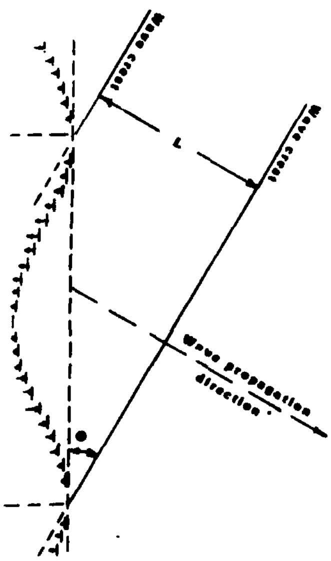

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DIRECTIONAL SPECTRAL WAVE GENERATOR BASIN RESPONSE TO MONOCHROMATIC WAVES

by

Michael J. Briggs, Mary L. Hampton

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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Final Report

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A series of 111 monochromatic waves was generated to determine the relationship between the directional spectral wave generator control signal and the measured response at nine locations in the model basin. Control signals consisted of combinations of five wave periods ranging from 0.75 to 3.0 sec, five strokes from 1 to 11 in., and five wave directions from 0 to 60 deg. Nine resistance-wire wave gages, spaced 10 ft apart within a 20- by 20-ft measurement area, were centrally located 10 ft in front of the wave generator about its center line. Comparisons are presented for measured versus predicted wave profile, period, height, and direction using linear, shallow-water wave theory; these comparisons reflect the influence of water leakage around and under the wave paddle due to the portable design. Thus, future monochromatic wave control signals can be corrected to obtain the desired wave conditions at different locations within the basin. Keywords;

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PREFACE

This report is a product of the Laboratory Simulation of Spectral and Directional Spectral Waves Work Unit, Coastal Flooding and Storm Protection Program, Civil Works Research and Development, at the US Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC). Testing was conducted from February to April 1986, and data reduction and report preparation were completed in April.

This report was prepared by Mr. Michael J. Briggs, Research Hydraulic Engineer, and Ms. Mary L. Hampton, Civil Engineering Technician, under direct supervision of Mr. Douglas G. Outlaw, Chief, Wave Processes Branch, and under general supervision of Mr. C. E. Chatham, Chief, Wave Dynamics Division, Mr. Charles C. Calhoun, Jr., Assistant Chief, and Dr. James R. Houston, Chief, CERC. Messrs. John H. Lockhart, Jr., and John G. Housley, Office, Chief of Engineers, were Technical Monitors for the Coastal Flooding and Storm Protection Program.

Numerous individuals contributed to successful completion of this project. In the WES Instrumentation Services Division (ISD), Mr. Barry W. McCleave, Electronics Engineer, wrote and developed much of the wave generation and measurement software and Electronic Technicians, Messrs. David A. Dailey and Lonnie L. Friar, operated and maintained the directional spectral wave generator, wave gages, and associated electronics. Also in ISD, Messrs. Homer C. Greer III and Selwyn W. Guy provided trouble-shooting services when electronic problems occurred. In CERC's Coastal Processes Branch, Mr. Norman W. Scheffner, Research Hydraulic Engineer, developed the nonlinear cnoidal waveform generation software and assisted with basin bathymetry measurements. In the Wave Processes Branch, Mr. Kent A. Turner, Computer Programmer Analyst, was invaluable for his day-to-day assistance with packages for wave analyses. Mr. Larry A. Barnes, Civil Engineering Technician, provided expertise in detailed design of wave absorbers and gage support frames, interfacing with the WES shops, and assisting with report preparation. Contract students, Ms. Christie T. Sanders and Mr. Larry D. Davis, generated control signals and helped with data reduction and report preparation. Mrs. Janie G. Daughtry and Mrs. Dorothy L. Staer, Branch Secretaries, prepared the final draft report. Ms. Jamie W. Leach of the WES Information Products Division edited this report.

Commander and Director of WES during publication of this report was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres

DIRECTIONAL SPECTRAL WAVE GENERATOR BASIN RESPONSE TO MONOCHROMATIC WAVES

PART I: INTRODUCTION

1. The directional spectral wave generator (DSWG) of the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) is a unique resource for study of natural sea states in a laboratory environment. It is the only one of its kind in the United States dedicated exclusively to simulation and analysis of naturally occurring short-crested waves in a coastal environment and wave processes associated with these waves. Some unique features are size, modular design, portability, method of paddle connection and displacement, and electric motor power. Basic monochromatic waveforms may be either linear sinusoidal or nonlinear higher order cnoidal. In addition to monochromatic waves, unidirectional and directional sea and swell components representative of different measured and empirical wave spectra can be simulated. Also, wave groups, wave transients, and other wave forms such as explosion waves can be simulated. The inclusion of directional spreading in design calculations for offshore and coastal structures may well result in less costly design. Coastal structures respond differently to three-dimensional wave environments than to two-dimensional waves. Three-dimensional waves create movements and forces transverse to the main wave direction that affect loads (Danish Hydraulic Institute (DHI) 1985). Thus, significantly improved physical model data can be obtained in site-specific and research studies using the DSWG facility and naturally occurring sea states.

2. In late 1985, the DSWG basin was relocated from its original position (used for acceptance testing from contractors) for more efficient utilization of model space in the movable-bed test facility and easier access to the computer control room. In the process, a new wave absorption system was designed, built, tested, and installed along the basin perimeter. New wave gage support frames also were designed and built. These frames allow multiple gages to be installed in a linear array with less interference from support legs. A centrally located power and gage connection box allows greater flexibility for relocating the DSWG and wave gages. Two catwalks located parallel to the DSWG permit easy overhead photography and cinematography.

3. Monochromatic performance tests were conducted from February to April 1986. A series of 111 monochromatic sinusoidal waves was generated to determine the relationship between DSWG control signal and the measured waves at nine different locations in the wave basin. The series consisted of combinations of five wave periods, heights (i.e. generator strokes), and directions. The wave periods ranged from 0.75 to 3 sec, the generator strokes from 1 to 11 in.,* and the directions from 0 to 60 deg. In addition, wave heights just prior to breaking were determined for the five wave periods by varying control signal stroke amplitudes. Effects of wave nonlinearity also were investigated by comparing linear sinusoidal results with cnoidal waveforms generated using second-order generator control theory. Thus, the purpose of these tests was to verify theoretical predictions and correct them as necessary, to ensure repeatability, to note any differences within the basin due to location and time, and to study the effects of nonlinearity.

4. In Part II, descriptions of the DSWG wave basin and wave generating, wave measurement, and data acquisition and control systems are given. Part III describes wavemaker theory, including two- and three-dimensional height transfer functions, maximum prebreaking wave heights, constancy of mean wave height, snake principle, spurious wave period limits, wave nonlinearity parameters, control signal generation, test design and averaging criteria, harmonic analysis, and wave analysis for height, period, and direction. Part IV documents test procedures used in the five project phases including theoretical predictions, control signal generation, wave gage calibrations, wave generation and measurement, and analysis. Test results are presented in Part V, and effects of wave maker period, stroke, and angle of propagation on wave profiles are shown. Results of comparisons between predicted and measured values for wave periods, heights, and directions are given in tabular and graphical form. Harmonic analysis of measured data shows the total percent variance contained in the first harmonic components. Also, maximum strokes required to generate prebreaking waves as a function of wave period are reported. The constancy of wave heights within the measurement area and along wave crests is described. Also, effects of nonlinearity on waveform and measured period and height are discussed. Finally, Part VI contains a summary of results and recommendations for future research and improvements.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

PART II: GENERAL DESCRIPTION OF FACILITIES

5. In this part, descriptions of the DSWG wave basin, wave generator, wave measurement, and data acquisition and control systems are given.

DSWG Wave Basin

6. The DSWG wave basin is housed in CERC's movable-bed test facility which contains approximately 70,000 sq ft of laboratory floor space. Figure 1 is a schematic illustrating the relative position of the basin to three other basins and the office/computer complex.

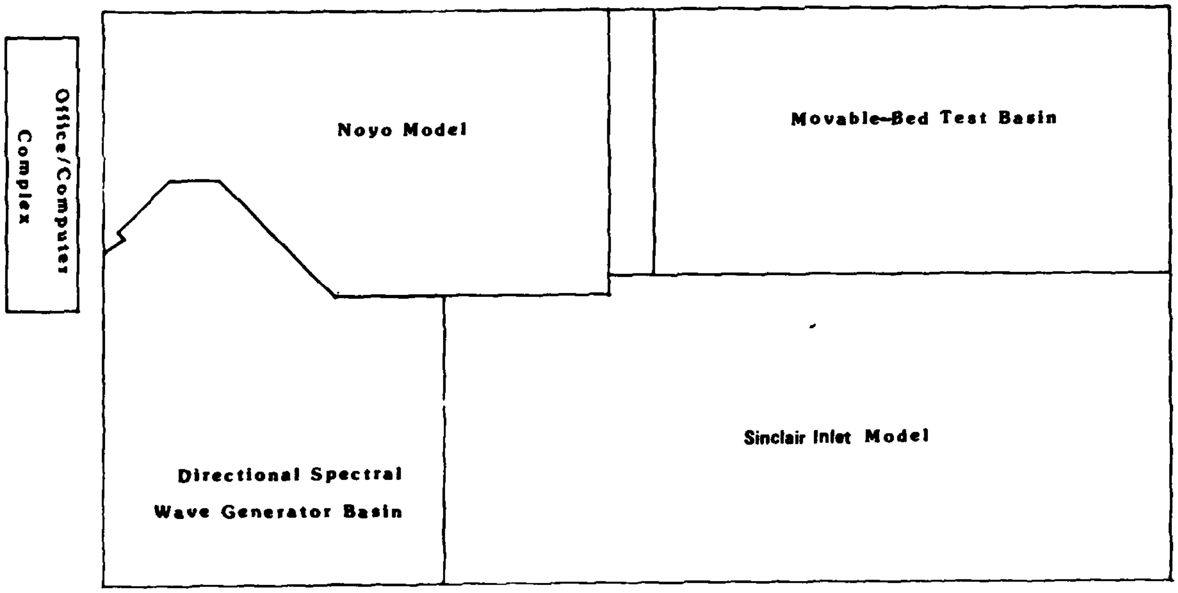


Figure 1. Location of DSWG basin within movable-bed test facility

Physical dimensions

7. The DSWG basin is 96 ft long by 114 ft wide and can accommodate water depths to 2 ft within its concrete block walls (Photo 1). The basin is within a larger irregular area which measures 138.3 ft long by 120.8 ft wide (Figure 2). Rather than erect a wall parallel to the DSWG to close off this area, it was decided to incorporate the irregular geometry to aid in wave absorption and energy dissipation behind the wave absorbers. The basin holds approximately 112,000 gal of water when filled to the 1-ft level.

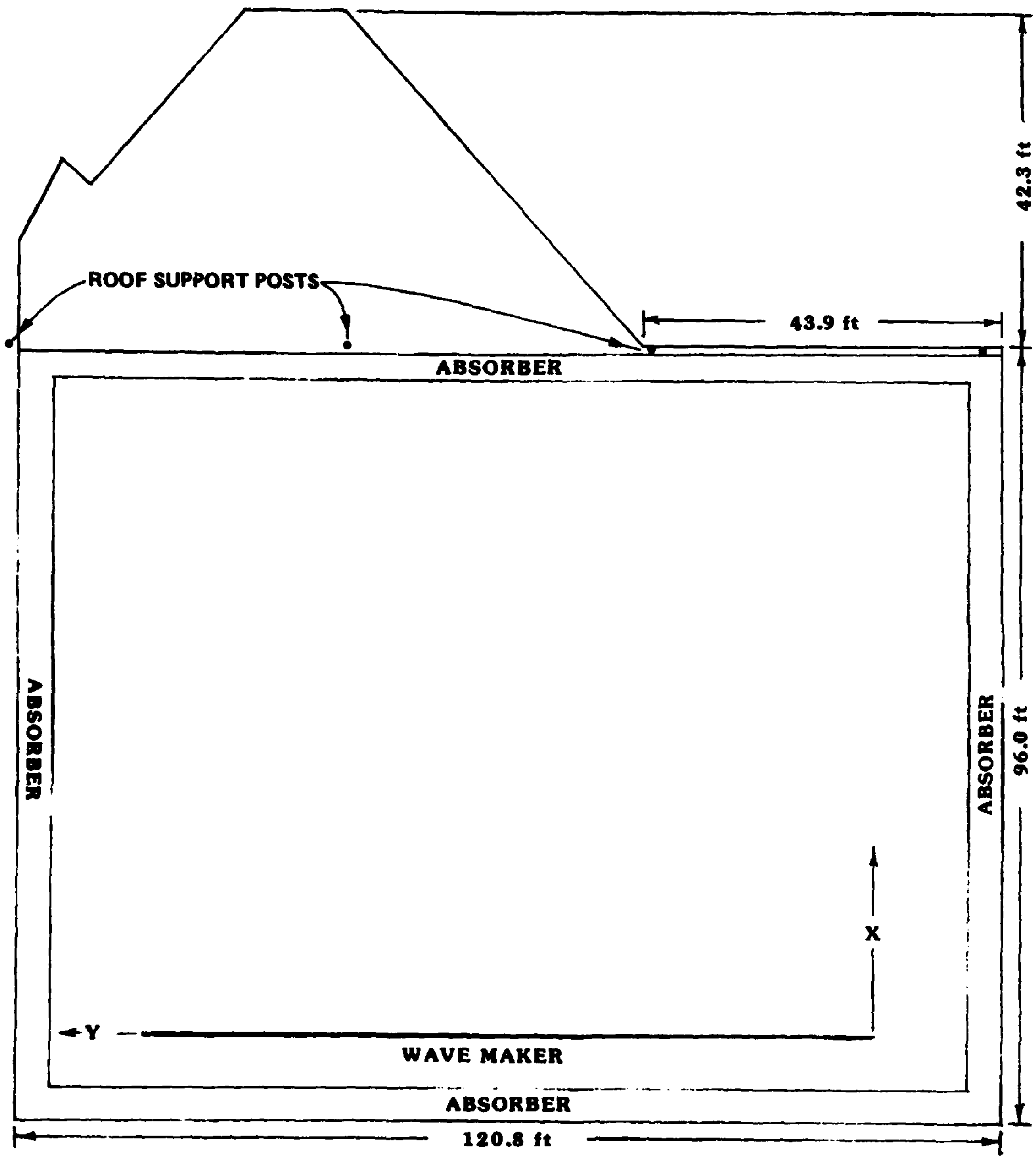


Figure 2. DSWG basin and coordinate system

Basin bathymetry

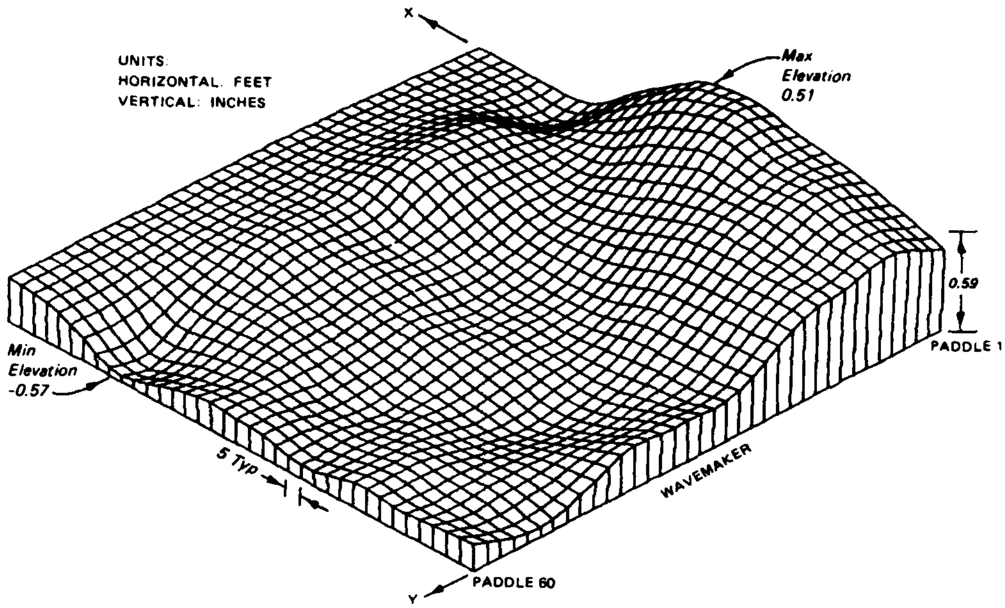
8. The bathymetry of the basin was measured at 5-ft intervals using a level and rod in the 70- by 90-ft area in front of the DSWG. Figures 3a and 3b are three-dimensional surface and contour plots of the DSWG basin, respectively, at interpolated 2.5-ft grid points on a 90- by 90-ft grid. A 0.8 smoothing factor was used for both. Because of the loss of resolution due to the smoothing factor, both surface and contour plots are only intended to illustrate relative trends and not absolute values. On the three-dimensional surface plot, the origin of the DSWG coordinate system is in the lower right corner (i.e. DSWG Paddle 1) and extends along the bottom to the center of the page (i.e. DSWG Paddle 60). On the contour plot, the DSWG extends along the bottom of the plot. The maximum variation in the basin bathymetry is 1.08 in. The highest point is +0.51 in. at coordinates X = 35 ft, Y = 5 ft. The lowest spot, measuring -0.57 in., is at coordinates X = 70 ft, Y = 80 ft. Standard deviation for the data set of 285 measurements is 0.18 in. Appendix A contains a tabular listing of the measured values.

Wave absorption system

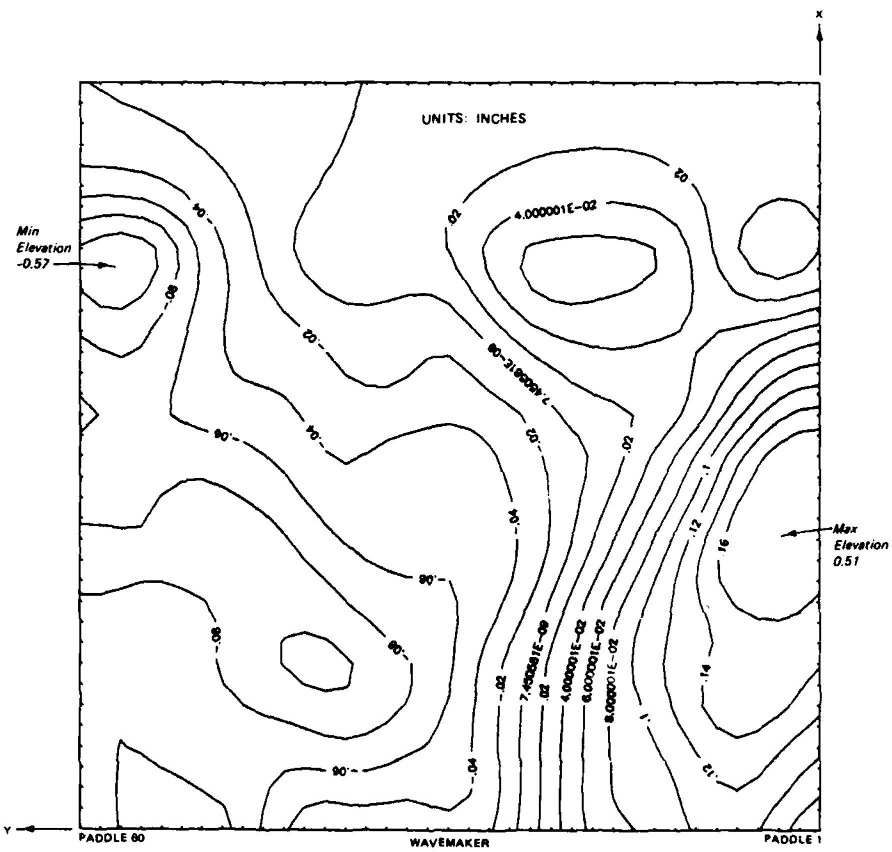
9. The DSWG basin has a unique beach/wave absorption system. Portable, metal frames with slopes of approximately 37 deg are installed along the basin perimeter, and frames behind the DSWG have two beach faces with individually adjustable slopes. Wave absorption and energy dissipation are provided by two layers of 2-in. horsehair sandwiched between two layers of expanded metal. Photos 2 and 3 show the wave absorber behind the DSWG and the beach wave absorbers opposite the DSWG, respectively. In flume tests of 16 selected cases covering wave periods from 0.75 to 3 sec and wavemaker strokes of 1 to 9 in., an average reflection coefficient of 12.25 percent was measured for the horsehair and expanded metal absorbers. Also, the irregular basin shape behind wave absorbers at the beach end tends to scatter wave energy outside the main wave basin. The DSWG basin is located inside an insulated steel frame metal shelter which has four center roof support posts (8 in. diam) spaced at 40-ft intervals behind the beach. Reflection and diffraction of energy from these support posts are insignificant because of their location.

Observation platforms

10. Two overhead catwalks parallel to the DSWG, one over the far end and one bisecting the basin, are excellent vantage points for photography and video documentation.



a. Surface plot



b. Contour plot

Figure 3. DSWG basin bathymetry

Wave Generating System

11. The DSWG was designed and built by MTS Systems Corporation of Minneapolis, Minnesota. It is the only one of its kind in the United States and measures 90 ft long, 4 ft 2 in. wide, and 4 ft 2-7/16 in. high (Photo 4). It consists of 60 paddles in 4 modules (i.e. 15 paddles per module), each 2.5 ft high and 1.5 ft wide. The paddles operate in a piston (translational) mode (more efficient and representative of shallow-water environments) and are driven at each of the 61 joints. This produces a cleaner, more continuous waveform with less cross-wave generation for wave periods greater than approximately 0.70 sec than does driving individual paddles (Sand 1979). Wave periods are typically above 0.6 sec. The range of strokes is ±6 in. corresponding to a ±10 volt input signal. Directional waves are generated using the "snake principle" (Part III). Offset angles between paddles can be continuously varied within the range of 0 to 180 deg to produce directional waves at angles approaching ±90 deg for most wave periods.

12. A unique feature of this generator is portability. The modular design (Figure 4) allows it to be moved to different locations within the movable-bed test facility for different projects. Photo 5 shows the front and back of an individual DSWG module. Thus, it is a "wetback" design with no bottom or end seals. Figure 5 is a schematic of the two drive plates, fixed

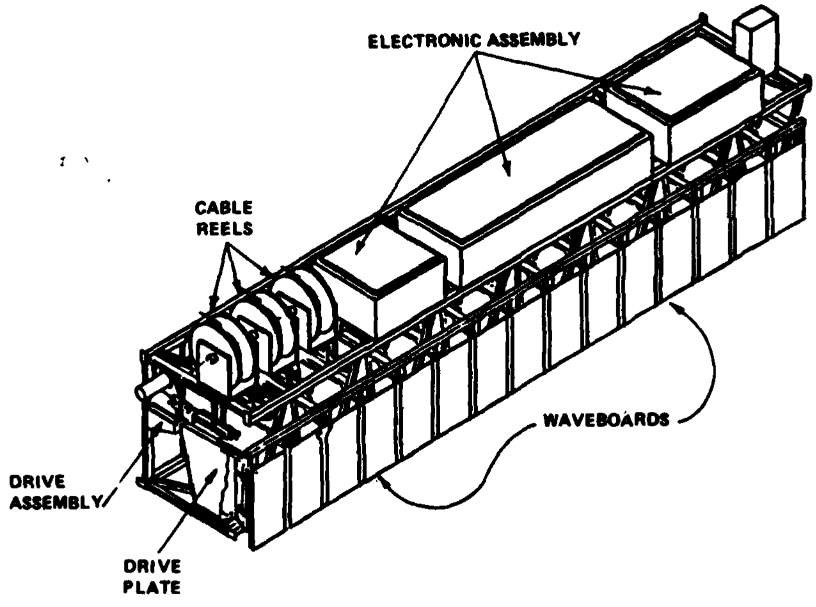


Figure 4. Modular design of DSWG

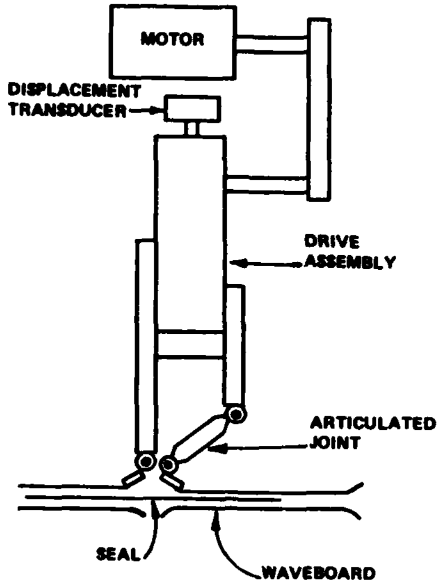


Figure 5. DSWG paddle design

and articulating hinges, and flexible plastic plate seals which slide in guides between each paddle to provide continuity. Four lifting points, two in front and two in back of each 7,250-lb module, are provided for transporting the DSWG. Six adjustable mounting pads are provided for leveling each module. Also, a catwalk and cable tray for interconnecting cabling and conduit are provided.

13. The DSWG is an electronically controlled, electromechanical system. Photo 6 is a close-up of the individual 0.75-hp electric direct current (DC) motors which drive each paddle joint. Rotary motion of these motors is converted to a forward/backward motion through pulley and drive assemblies. Also contained on each module are four Hoffman enclosures: (a) power disconnect enclosure for the power breaker switch and main power fuses for 460-v, 60-Hz, 3-phase at 22-amp power (Photo 7); (b) power distribution enclosure for main power with four transformers, power distribution terminal boards, and one convenience outlet (Photo 8); (c) pulse width modulated (PWM) servo motor controllers enclosure containing three PWM controllers, power supply, controllers, and cooling fans for power and signal conditioning (i.e. Getty amplifiers, Photos 9 and 10); and (d) Temposonics transducer modules enclosure for control and feedback transducers for monitoring paddle position (Photo 11). Also located on each module are three 400-ft-long power and control cables and take-up reels for electrical interface with the system control console. Cable

reel 1 controls drive disable and power on/off. Cable reel 2 carries the drive command. The displacement feedback is controlled by cable reel 3.

14. A wave generator control console, also built by MTS, is located in the computer control room. Photo 12 shows front and rear views of this console. It includes both digital and analog circuits and provides digital wave board control signals from the VAX 11/750 computer for input to 61 Preston D/A converters using an IEEE 488 interface for each of 61 D/A driven servo modules. This console weighs 875 lb and is 5 ft wide, 3.5 ft deep, and 6 ft high. Bay 1 contains a calibration/test indicator, three MTS 450 servo/controller chassis with 10 servo controller modules (which provide drive command, drive enable/disable, and displacement readout signals) each, and two connector panels for controlling modules 1 and 2. Bay 2 is similar to Bay 1 with electronics for controlling modules 3 and 4. An additional servo controller module is provided for a total of 31 in Bay 2 (i.e. 61 total for system). Also, a power distribution box for two 26-v DC power supplies, two DC voltmeters, one input connector plug, and six output connector plugs are included. Finally, Bay 3 contains one Preston D/A controller, 12 ft of IEEE 488 cable, four D/A converter chassis with 61 Preston D/A converter modules, the system control panel, and the power entry panel for 120-v, 60-Hz, 1-phase, 22-amp power. Necessary connections, interface cabling, backplane wiring, cooling fans, and power plug mold strips are provided as required. A function generator is provided for calibration checking of the system. Photo 13 illustrates the module power "on" and "off," emergency stop, master reset, and program "run" and "stop" buttons on the system control panel. Also, stroke and displacement error limits and operating range adjustments including program span, displacement set point, error gain and rate, drive zero, and error zero are provided by a servo module panel for each drive (Photo 14). Interested readers should refer to the paper by Outlaw (1984) and the MTS 927.57 Instruction Manual (MTS System Corporation 1984) for more details of this system.

Wave Measurement System

Measurement area

15. A 20-ft-sq measurement area, located parallel to and 10 ft from the DSWG (symmetric about its center line), was selected for these experiments. Nine wave gages were installed with 10-ft spacings. For waves generated by

the snake principle, the best measurement area is as near the generator as possible, but a minimum distance of 3 to 10 water depths in front of it (Goring and Raichlen 1980) to avoid diffraction and finite length effects. Also, to minimize effects of reflected energy, the measurement area should be as close to the generator as possible to maximize the time for measurement before reflected waves return. As wave direction increases, usable measurement area decreases because limiting wave rays leaving the ends of the DSWG are at such a steep angle that they cut through the measurement area. Figure 6 shows the measurement area and the maximum wave direction angle of 49 deg which could be generated and still permit measurement by all gages. For the 60-deg wave direction, only Gages 1, 2, 3, and 6 could be used for measurements.

Wave gages

16. The wave gages are parallel wire resistance-type sensors. They measure the change in water surface elevation with time and record it as a

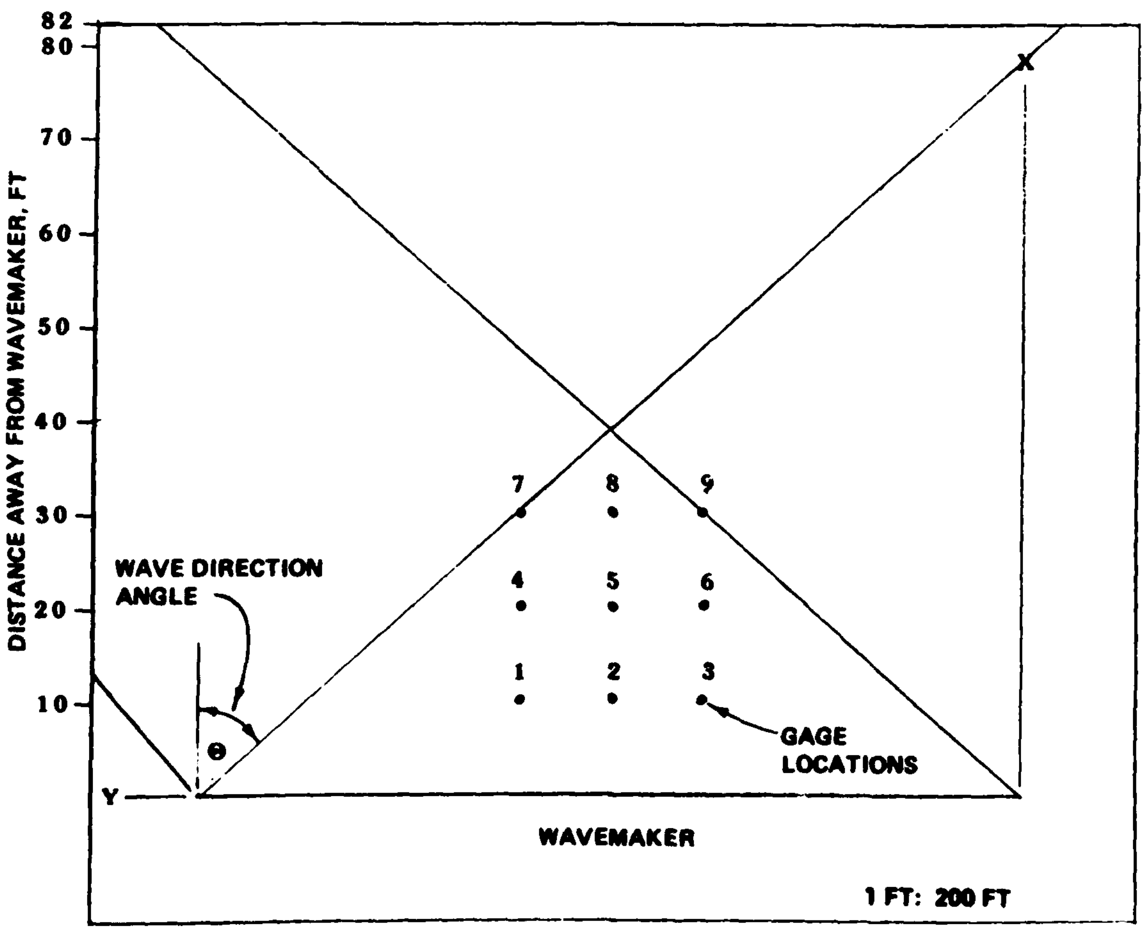


Figure 6. Measurement area and maximum measurable wave angle

voltage which is later converted to a wave elevation time series by analysis software. Because resistance-type gages are conductivity probes, they are very sensitive to electronic and temperature drift and cleanliness of the water (i.e. dirt, oil, etc.). Two sizes of wave gages were used in this study. "Small" gages have a maximum calibration range of 3.25 in. Larger "Jordan" gages have a calibration range of 10 in. The small gages provided better resolution where wave heights did not exceed their range.

Gage support frames

17. Three aluminum wave gage support frames, 22 ft in length, were designed and installed in the measurement area. The frames reduce possible interference with the wave train by support legs. Photo 15 gives different views of these frames.

Data Acquisition and Control System

18. An automated data acquisition and control system (ADACS) is used to generate and transmit control signals, monitor DSWG feedback, and analyze and store measured data. The heart of the ADACS for the DSWG is a DEC VAX 11/750 computer. Table 1 summarizes computer specifications and system components. The DSWG control signal is updated 20 times per second, and data for each measurement channel are sampled at a 50-Hz sampling frequency.

PART III: WAVEMAKER THEORY

19. The wavemaker theory discussed in this part assumes linear wave theory for plane piston wavemakers in shallow water, and standard assumptions that the fluid is incompressible and irrotational are made. Descriptions of wavemaker theory including two- and three-dimensional height transfer functions, maximum prebreaking wave heights, constancy of mean wave height, snake principle, spurious wave period limits, wave nonlinearity parameters, control signal generation, test design and averaging criteria, harmonic analysis, and wave analysis for height, period, and direction are given.

Wave Height Transfer Function

20. Biesel (1954) originally derived the two-dimensional transfer function F_2 describing the ratio of generated wave height H to wavemaker stroke S.* By equating the volume of water displaced by a piston wavemaker to crest volume in the waveform, Galvin (1964) showed that the asymptotic approximation for this transfer function is given by

$$F_2 = \frac{H}{S} = kh \qquad kh < \pi/10 \tag{1}$$

where

k = wave number

h = water depth

21. Madsen (1974) and Dean and Dalrymple (1984) describe the procedure used to obtain the complete wavemaker theory for plane waves produced by a piston wavemaker. The boundary value problem for the wavemaker involves solution of the governing velocity potential equation (i.e. Laplace equation) with appropriate boundary conditions. These conditions are the dynamic and kinematic free surface, kinematic bottom, and radiation boundary conditions. By combining these into a kinematic wavemaker boundary condition describing the horizontal displacement and velocity of the wavemaker, neglecting higher order

* For convenience, symbols and abbreviations are listed in the Notation (Appendix G). An effort has been made to conform with the terminology recommended by the IAHR (International Association for Hydraulic Research) Working Group on Wave Generation and Analysis (1985).

terms (i.e. linearizing) and invoking orthogonality conditions, the complete two-dimensional transfer function F_2 can be shown to be

$$F_2(f) = \frac{H}{S} = \frac{2 \cosh (2kh - 1)}{\sinh (2kh) + 2kh} \tag{2}$$

An equivalent form, based on trigonometric substitutions, is given by Sand (1979) and Sand and Lundgren (1981) as

$$F_2(f) = \frac{H}{S} = \frac{2 \sinh^2 (kh)}{\sinh (kh) \cosh (kh) + kh} \tag{3}$$

Equations 2 and 3 are valid over all ranges of nondimensional depth kh .

22. Standing waves which the wavemaker may create due to mismatch with the water particle horizontal velocity are assumed to decay rapidly with distance from the wavemaker. Thus, measurements are usually made several water depths or wavelengths in front of the wavemaker.

Directional Effect on Wave Height Transfer Function

23. The three-dimensional wave height transfer function F_3 includes the effects of wave directionality on wave height. Using Huygens principle and energy flux arguments, Sand (1979) showed how F_3 is an extension of F_2 for multiple, piston type, infinitely small paddles. To first order, F_3 is given by

$$F_3(f,\theta) = \frac{F_2(f)}{\cos \theta} = \frac{H(\theta)}{S} \tag{4}$$

where

θ = wave direction

$H(\theta)$ = corrected wave height

Maximum Prebreaking Wave Heights

24. For piston wavemakers, the maximum monochromatic wave height which

can be generated at the wavemaker H_b has been empirically derived by Ahrens* as:

$$H_b \approx 0.1L \tanh (kh) \tag{5}$$

where L = linear, shallow-water wave length. Breaking of the waves at the wavemaker tends to occur if a constant larger than 0.1 is used in Equation 5. This relationship does not rule out the possibility of waves larger than this occurring at points within the basin as a result of shoaling, etc. It only provides that they do not break at the wavemaker because of the discontinuity of the paddle motion. Equation 5 is in agreement with Naeser (1981) for a practical breaking limit $H/L = 0.1$ for wave periods less than 1.6 sec.

Constancy of Mean Wave Height

25. The mean wave height variation $\Delta\bar{H}$ is a measure of the constancy of wave height along a wave front within the measurement area. It is defined in percent as

$$\Delta\bar{H} = 100\left[\sum_{n=1}^{9} \frac{(H_n - \bar{H})}{9\bar{H}}\right] \tag{6}$$

where

H_n = wave height measured at wave gage n

$\bar{H}$ = average wave height of the nine gages within the measurement area

Sand (1979) found a range in $\Delta\bar{H}$ in his experiments of $\Delta\bar{H} < 15$ percent for directions $\theta \leq 10$ deg and $\Delta\bar{H} < 25$ percent for $10 < \theta \leq 25$ deg.

26. Possible sources of wave height variation in wave basins are the interaction of free and bound higher harmonics, reflections, end diffraction, Benjamin-Feir instability, basin assymmetry, variable wavemaker strokes, variable bottom gap, and calibration errors. In nature, waves are characterized by a higher, sharper crest and flatter trough than predicted by linear,

* Personal Communication, January 1986, John P. Ahrens, Research Oceanographer, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

first-order wave theory. This is due to a second-order effect of a bound or locked higher harmonic (second harmonic will have greatest amplitude) wave (BHW) which consists of sums of fundamental frequencies. If first-order wave theory is used for calculating the wavemaker control signal, boundary conditions at the wavemaker cannot be satisfied for the second-order BHW, resulting in the creation of spurious or free higher harmonic waves (FHW). The result in a wave basin is a continually changing wave profile as a function of position due to alternating cancellation and reinforcement with the BHW component. As the water-depth-to-wave-length ratio decreases, a sinusoidal control signal transforms in a basin into a nonlinear waveform by binding a second harmonic BHW to the fundamental wave. In the process, an FHW is liberated which distorts the wave profile as described above (Sand and Mansard 1985; Briggs 1986).

27. Reflections are another major contributor to wave height variability in wave basins. A reflection coefficient of 10 percent results in a wave height variation of ±10 percent. Reflections are greatest for waves with periods larger than 2 sec because low frequency energy is less easily absorbed. Also, during reflection, wave energy is transferred between BHW and FHW waves as the fundamental wave is partly absorbed, partly reflected, and partly converted to FHW waves (Mansard, Sand, and Funke 1985).

28. Energy can be diffracted from the ends of a wavemaker that is not sealed at the ends. These diffracted waves affect the measurement area directly and also reflect off side boundaries into the measurement area.

29. According to Funke,* low frequency standing cross waves due to mean water level changes in a shallow-water basin might act to modulate a basic sine wave component causing shedding of energy to different frequency bands, producing a type of "Benjamin-Feir" effect.

30. A variable bottom gap between the bottom of individual paddles in the wavemaker and the wave basin floor will produce smaller and more spatially variable wave height than theoretically predicted. Also, if transducers controlling the amount of stroke going to each paddle are out of calibration, slight variability in generated wave heights could result. According to Madsen (1971, 1974) leakage and turbulence adjacent to the wavemaker produce variability in wave height.

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* Personal Communication, 29 May 1986, E. R. Funke, Senior Research Officer, Hydraulics Laboratory, National Research Council of Canada, Ottawa, Ontario, Canada.

31. Finally, assymmetry of the wave basin can produce complicated reflection patterns as the beach response is not uniform. Also, calibration tolerances of the wave gages will affect measured values. Thus, it is normal to expect a certain amount of variation in measured wave heights due to a combination of one or more of these causes.

Snake Principle

32. The DSWG utilizes the snake principle to generate waves with directions approaching ±90 deg. This terminology evolved because the wavemaker looks more or less like an undulating snake as the waveform progresses along its length. For monochromatic waves, energy is generated at a discrete frequency and direction using a constant phase lag or offset angle between paddles. Several authors have described the procedure including Naeser (undated) and Offshore Technology Corporation (1984). The angle of wave propagation or wave direction θ is determined by

$$\sin \theta = \frac{L}{Y} \tag{7}$$

where Y = distance along the wavemaker corresponding to one period or cycle of 360 deg (Figure 7). The distance Y is related to the paddle width B by

$$Y = N_{\ell}B \tag{8}$$

where N_{ℓ} = number of paddles required to make one cycle and is a function of the offset phase lag ϕ

$$N_{\ell} = \frac{360}{\phi} \tag{9}$$

Figure 8 illustrates how the angle of wave propagation changes as the sign of the phase angle changes.

33. Naeser et al. (1981) and Sand (1979) note that the generation of "snake waves" is restricted for periods below 1 sec because of the need to have a minimum of two paddles over the cycle distance Y (i.e. phase lag of 180 deg). Thus, for the 0.75-sec period, it is not possible to generate waves

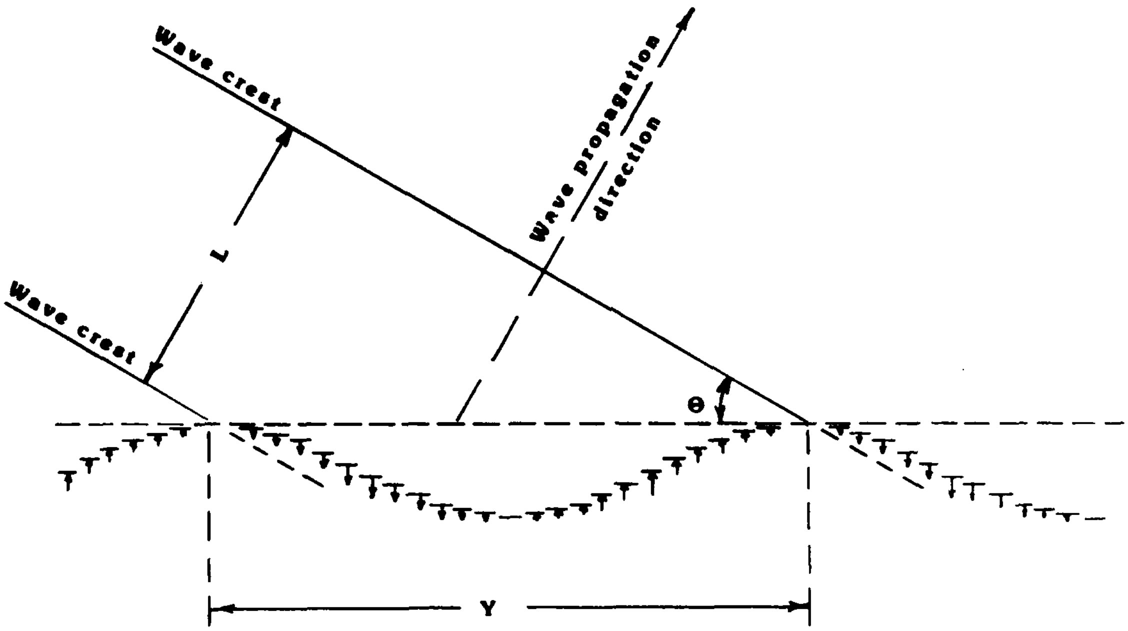


Figure 7. Snake principle for generating waves

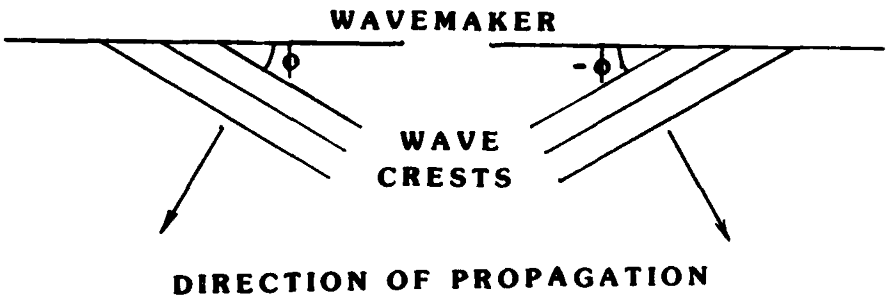


Figure 8. Direction of wave propagation relative to phase angle

up to ±90 deg. A more realistic maximum wave direction angle is approximately 70 deg for an offset phase of 179.1 deg. For an integer number of paddles as used in these tests, the maximum wave angle declines to 38.8 deg for this wave period. Table 2 lists the values for the offset and direction angles for exact and integer number of paddles over a wavelength. The maximum wave direction angles for an integer number of paddles were used in this study. The DSWG can generate waves within a continuous range of angles as long as two or more paddles are used.

Spurious Wave Period Limits

34. As a consequence of the finite width of the wavemaker paddles, small undesired disturbances known as spurious waves, distinct from the spurious waves discussed in paragraph 26, are generated in addition to the main waves. The number of these waves is fixed by paddle width and wavelength, and their frequency is the same as that of the main wave. Amplitude and directions, however, change for each spurious wave component p. Spurious wave amplitudes, small relative to the main wave, are attenuated even more as the number of spurious wave components increases. The DSWG is driven at the joints between the paddles rather than at the center of individual paddles (Figure 5). Although this does not change the number of spurious waves which may be generated, Sand (1979) and Sand and Lundgren (1981) showed that it does greatly attenuate the amplitude of waves which might be produced.

35. According to Naeser et al. (1981), the minimum period T_{min} necessary to prevent spurious waves is defined by

$$T_{min} = 0.53\sqrt{\sqrt{2} + \sin\Theta} \tag{10}$$

where Θ = angle between the wave crest and the wavemaker. Figure 9 illustrates this relationship. Table 3 is based on Sand's results and lists the number of spurious waves generated for wave periods less than 1.0 sec with the range of wave directions given. Because waves with periods less than 0.75 sec were not considered in this study, spurious wave generation did not pose a serious problem.

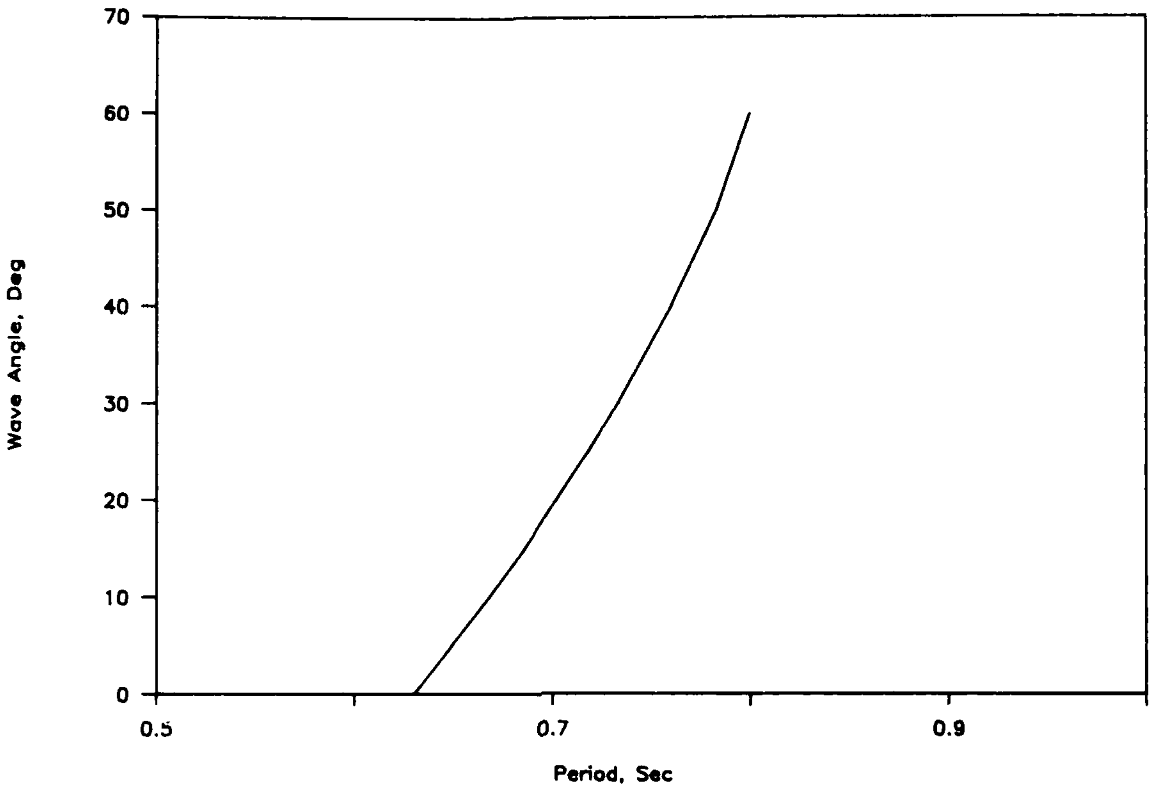


Figure 9. Minimum spurious wave periods

36. The wave height of the p^{th} spurious wave component H_p is

$$H_p = H(\Theta)\left[\frac{\sin\left(\frac{\pi}{N_\ell}\right)}{\pi\left(p - \frac{1}{N_\ell}\right)}\right]^2 \qquad p = 1,2... \tag{11}$$

where $H(\Theta)$ = wave height of the main wave corrected for directional effects (see paragragh 23 on directional effects on wave height transfer function).

37. Sand also showed that the direction Θ_p of the p^{th} spurious wave is given by

$$\Theta_p = \sin^{-1}\left[\frac{L(1 - pN_\ell)}{Y}\right] \qquad p = 1,2,... \tag{12}$$

Wave Nonlinearity Parameters

38. Certain wave height and period combinations produce waves which tend to deviate from the linear Airy wave profile (i.e. sinusoidal). The waves tend to become more nonlinear: higher, sharper crests and broader, flatter troughs. Higher harmonic components become more pronounced in the wave profile on the back side of the crest and in the troughs. This phenomenon is due to mismatch in wavemaker motion with the required water particle velocities. As the waves become more nonlinear, it is necessary for the wavemaker to move forward faster, and slower coming back. Descriptions of the control signal generation for both linear and nonlinear cnoidal control therry waveforms are given in the next section.

39. Measures of wave nonlinearity are the wave steepness H/L and Goda's (1985) nonlinearity parameter Π defined as

$$\Pi = \frac{H}{L} \coth^3 (kh) \tag{13}$$

Whereas the Ursell number is only appropriate for shallow-water conditions, Goda's parameter can be used for all water depths and reduces to Ursell's for shallow water. It appears that waves with values of Π less than 0.1 are relatively linear with the nonlinearity increasing above this value. Comparisons of wave period and height with this parameter are made in Part V.

Control Signal Generation

40. The primary type of control signal was a linear sinusoidal wave. To ascertain effects of nonlinearity on higher waver periods, nonlinear cnoidal control signals also were generated. Orientation of the coordinate system is the same as in Figure 2 with the origin at the outer edge of paddle 1, the x-axis extending perpendicular to the wavemaker, and the y-axis parallel to the wavemaker.

Linear sinusoidal waveforms

41. For the sinusoidal waveform, the governing equation for control signal S_c to each of the 61 pistons at location y and time t is

$$S_c(y,t) = \frac{S}{2} \cos (2\pi ft + \phi_y) \tag{14}$$

where stroke S, frequency f, and phase ϕ_y are input quantities. The wave height at a particular location in the basin is a function of the three-dimensional stroke-to-height transfer function previously discussed.

42. The phase ϕ_y consists of a constant portion and an offset portion which determines the wave angle generated. The constant portion was taken as zero. The wave is propagated along the wavemaker at the proper angle by offsetting successive paddles by the offset phase. This offset portion is maintained for the entire time of wave generation. The phase automatically recycles every 360 deg.

43. The stroke time-history is converted to a voltage time-history using the wavemaker conversion factor. Since 20 v = 12 in. for the maximum possible stroke and the A/D converter has a resolution of 4,096 digital units, the corresponding factor is 341.33 digital units/in. or a resolution of 0.00293 in.

Nonlinear cnoidal waveform

44. In the generation of shallow-water long waves with constant shape, Goring and Raichlen (1980) noted that it is important to consider nonlinear aspects. His method eliminates the trailing waves ("oscillatory tail") usually present. The velocity of the paddle as it moves is matched with the depth-averaged water particle velocity. The governing equation for the paddle displacement time-history $\xi(t)$ is

$$\xi(t) = \frac{H}{kh} \int_0^{\Theta} f(w)\, dw \tag{15}$$

where

$\Theta = k(Ct - \xi)$

C = celerity

$f(w)$ = function of Θ

w = dummy variable of integration

45. A cnoidal waveform time series with 360 increments is generated based on input water depth and desired wave height and wavelength. Because the cnoidal waveform is different from the sinusoidal, period and wavelengths

do not match exactly with those predicted by linear wave theory. For uniformity, the same wave periods were used for the cnoidal wave control signals, and the wavelengths were allowed to change as necessary.

46. Each of the 360 elements of the cnoidal waveform are matched to the appropriate phase for each paddle at each time step. The total phase $\phi_t = 2\pi ft + \phi_y$ is the same one described in the paragraphs above. The first part controls the frequency increment over a cycle, and the second part consists of a constant and offset component. Again, the constant portion is set to zero, and the offset is a function of the wave angle desired.

47. Finally, the control signals for all 61 pistons are converted to the corresponding voltage time series using the procedure previously described.

Test Design and Averaging Criteria

48. In defining the basin response to different wave conditions, it is preferable to obtain as many averages of the measured parameters as possible. All waves averaged need to be uniform in quality. At the beginning of wave generation, the DSWG imposes a 10-sec ramp time to protect system components. Also, a minimum number of waves must be generated to ensure that enough time has elapsed for the waves to travel to the wave gages. As the wave generation continues, the Benjamin-Feir (Benjamin and Feir 1966) instability may cause the waves to oscillate in amplitude with time. Also, reflected energy could contaminate the measured signal. Although flume tests over the range of periods used indicated reflection coefficients averaging 12.3 percent for the new wave absorber beach, any reflected energy would tend to degrade the incident waves. Therefore, test cases were run to determine the maximum number of waves which could be averaged for each period. The predicted travel times for the first wave to go to the back gage row and to reflect off the back wall and return were compared with measured values.

49. Figures 10a-10e illustrate the travel paths of wave rays from the left and right ends of the wavemaker through one complete reflection for each angle of wave propagation, 0 to 60, respectively. The travel time T_1 to the back gage row located 30 ft from the wavemaker is given by

$$T_1 = \frac{30}{C_g \cos \Theta} \tag{16}$$

where C_g = group velocity. The analogous travel time T_2 to reflect off the back wall (i.e. 134 ft = 82 ft from wavemaker to back wall plus 52 ft from back wall to back gage row) and return is

$$T_2 = \frac{134}{C_g \cos \theta} \tag{17}$$

Even though the wave ray may undergo several reflections prior to returning to the back gage row (i.e. 45 deg and 60 deg), the total distance traveled parallel to the x-axis is the same.

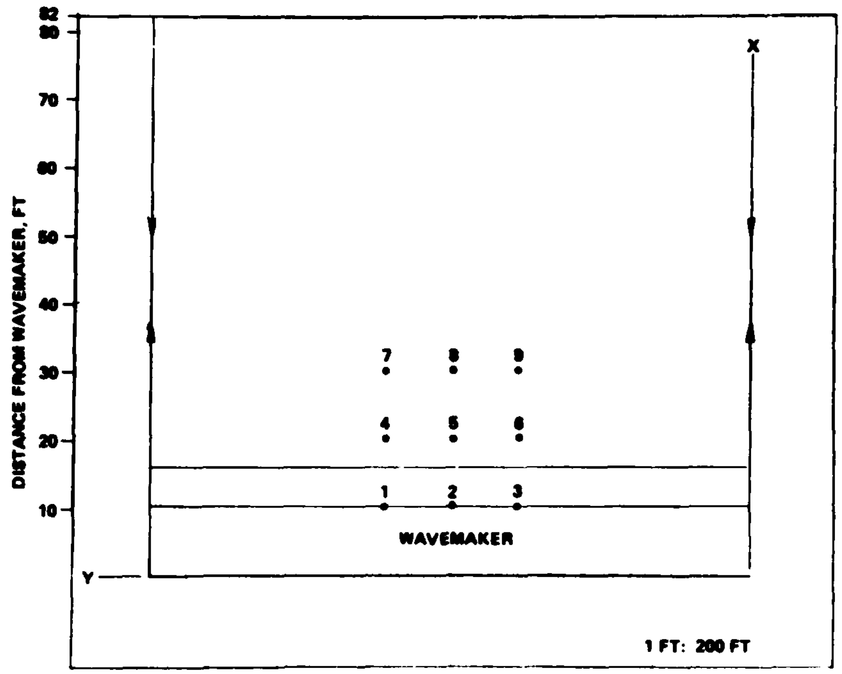
Zero-Crossing and Harmonic Analysis

Zero-crossing

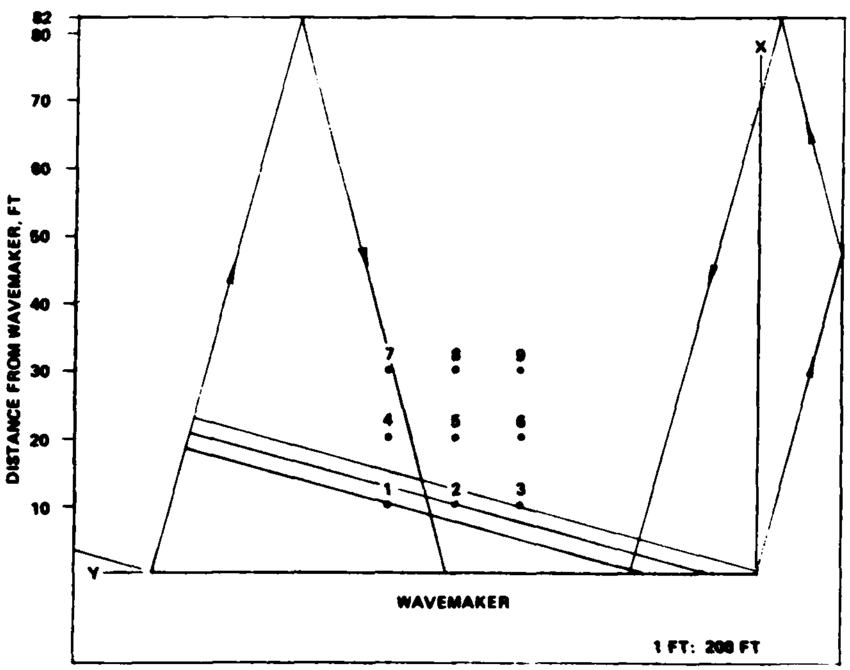
50. Two types of wave analysis are performed on the equally spaced measured data: zero-crossing and harmonic analysis. Zero-crossing analysis calculates average and significant wave heights and periods and their standard deviations using a windowing technique based on the specified period. Each windowed segment of the data is searched for the minimum and maximum value, assuming that each crest must follow a trough and the calculated period is within a specified tolerance of the generated period. Figure 11 is a flowchart of the search procedure from a report by Turner and Durham (1984). During the search process, the raw, unscaled, integer voltages are used because integer arithmetic is faster and requires less memory than floating point numbers. The data are later scaled by the calculated calibration coefficients using a linear or quadratic fitting procedure. This type of analysis is very sensitive to choice of window length and tolerance on the wave period specified.

Harmonic

51. The least-squares harmonic analysis is based on a Legendre method to fit a series of four components (for this analysis) to the measured wave elevation time series (Turner and Durham 1984). The purpose of this analysis is to ascertain the "purity" of the measured waveform by calculating the amount of total energy contained in the fundamental frequency and three higher harmonic components. Ideally, 100 percent of the variance is contained in the fundamental frequency component. If a linear control signal is used to

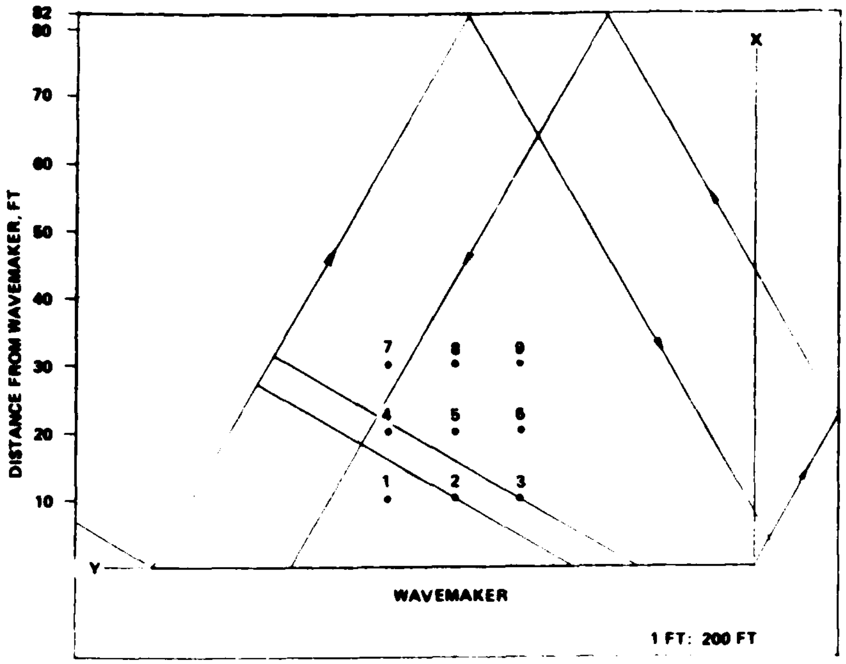


a. Wave direction = 0 deg

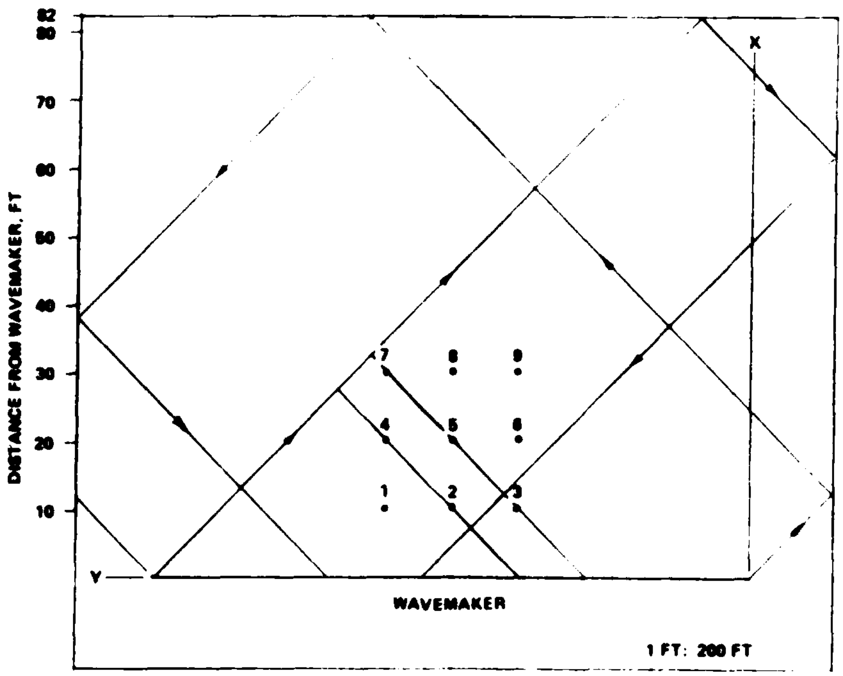


b. Wave direction = 15 deg

Figure 10. Limiting wave rays (Sheet 1 of 3)

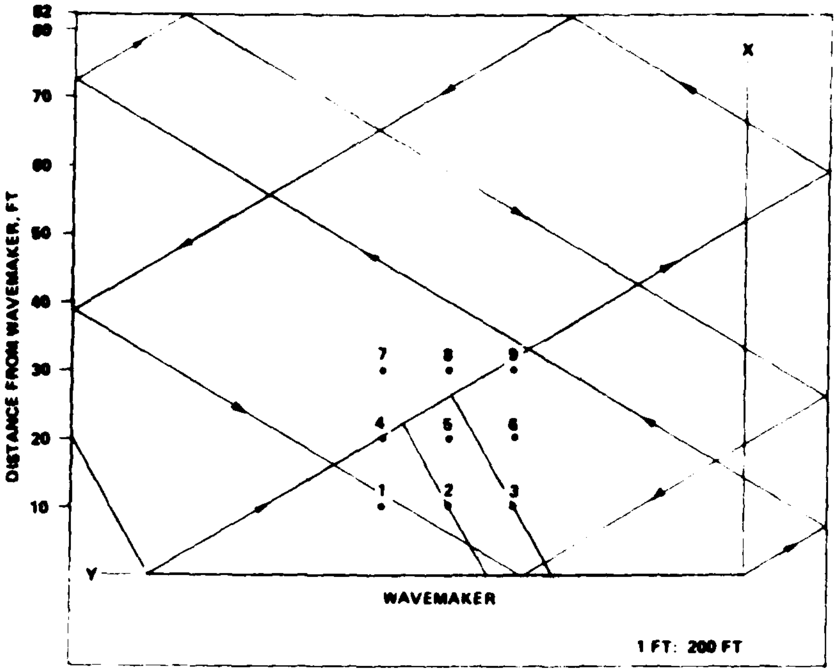


c. Wave direction = 30 deg



d. Wave direction = 45 deg

Figure 10. (Sheet 2 of 3)



e. Wave direction = 60 deg

Figure 10. (Sheet 3 of 3)

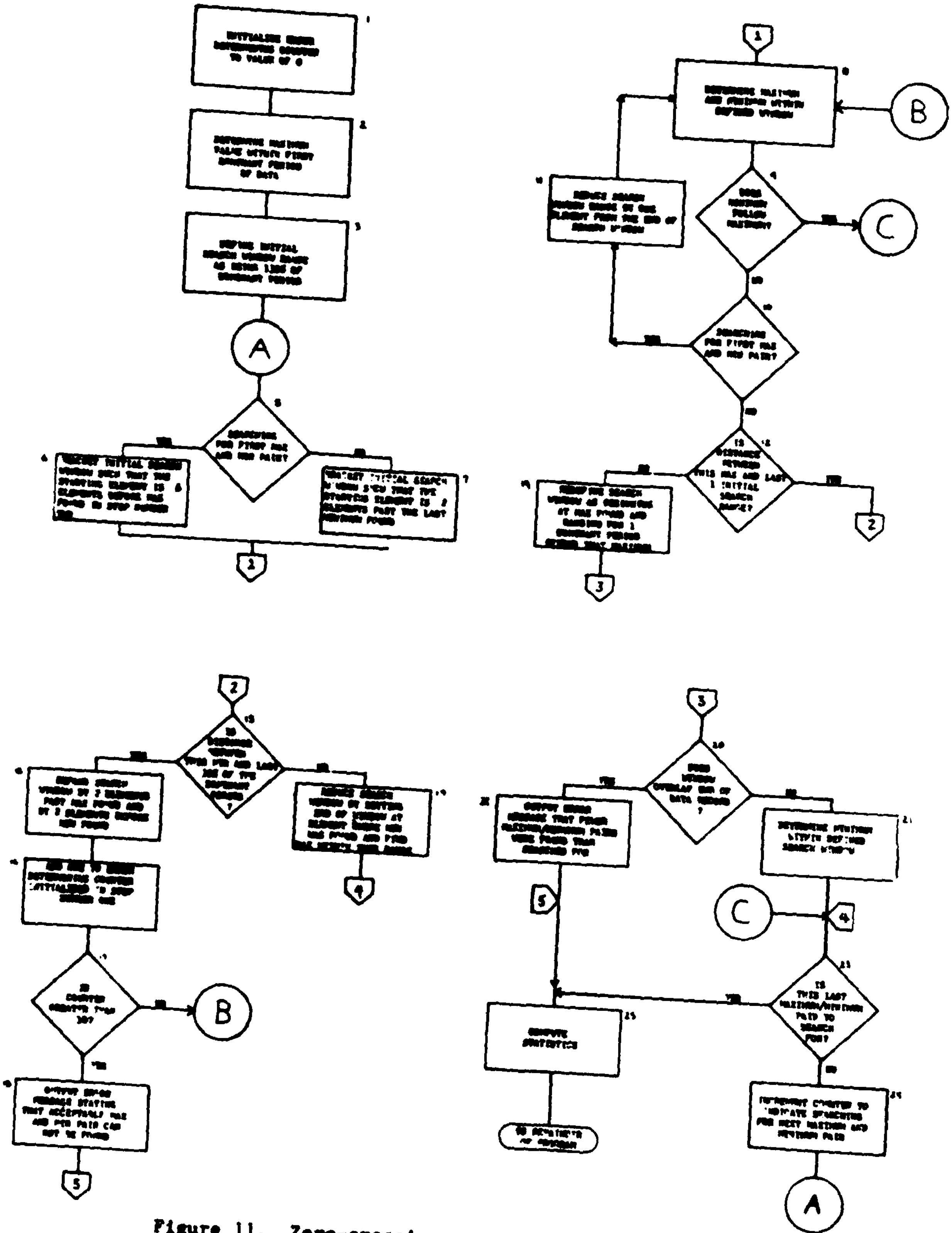


Figure 11. Zero-crossing analysis search procedure (after Turner and Durham 1984)

generate a wave which is highly nonlinear, energy will be shifted to harmonics of the fundamental in an attempt to produce the nonlinear wave profile.

52. The measured water surface elevation time series $\eta_m(t)$ can be assumed to be periodic in form and composed of a true component $\eta_t(t)$ and a noise component $\varepsilon(t)$ given by

$$\eta_m(t) = \eta_t(t) + \varepsilon(t) = a_0 + \sum_{j=1}^{J} a_j \cos(\omega_j t) + b_j \sin(\omega_j t) + \varepsilon(t) \qquad (18)$$

where

J = total number of components

a_0, a_j, and b_j = Fourier coefficients

ω_j = angular frequency of the j^{th} component

The noise level is not known and the unknown Fourier coefficients are determined by a least-squares procedure which minimizes the variance E such that

$$E = \sum_{n=1}^{N} \varepsilon^2(n\Delta t) = \sum_{n=1}^{N} \left[\eta_t(n\Delta t) - \eta_m(n\Delta t)\right]^2 \qquad (19)$$

where

N = total number of data samples

Δt = time interval (i.e. 0.02 sec) between consecutive samples

To minimize the variance, calculate

$$\frac{\partial E}{\partial a_j} = 0 \qquad j = 1,2,\ldots,J \qquad (20)$$

and

$$\frac{\partial E}{\partial b_j} = 0$$

Equation 19 results in a set of $2J$ simultaneous equations that may be solved for the a_j and b_j coefficients. It may be rewritten as

$$\eta_t(t) = A_0 + \sum_{j=1}^{J} A_j \cos(\omega_j t + \phi_j) \qquad (21)$$

where the amplitude A_j and the phase ϕ_j of the j^{th} component are determined from the Fourier coefficients

$$A_j = \sqrt{a_j^2 + b_j^2} \qquad (22)$$

and

$$\phi_j = \tan^{-1}\left(\frac{b_j}{a_j}\right)$$

and A_0 = mean water surface elevation. Thus, a true or estimated surface elevation time series is calculated from which percentage of total variance for each frequency can be determined.

Wave Direction Analysis

53. The direction of wave travel is calculated by computing travel time for a wave front to travel between any two gages in the array. This travel time can be calculated using cross-correlation techniques or measured manually. In this study, the latter approach was used.

54. Figure 12 illustrates the procedure for calculating wave direction. The travel time Δt for a wave to go from Gage 2 to Gage 3 is measured from the respective time series plots based on phase lag. The incremental wavelength ΔL then is given by

$$\Delta L = C\Delta t \qquad (23)$$

The measured wave direction θ_m then is

$$\theta_m = \sin^{-1}\left(\frac{\Delta L}{\Delta y}\right) \qquad (24)$$

where Δy = distance between gages parallel to the wavemaker.

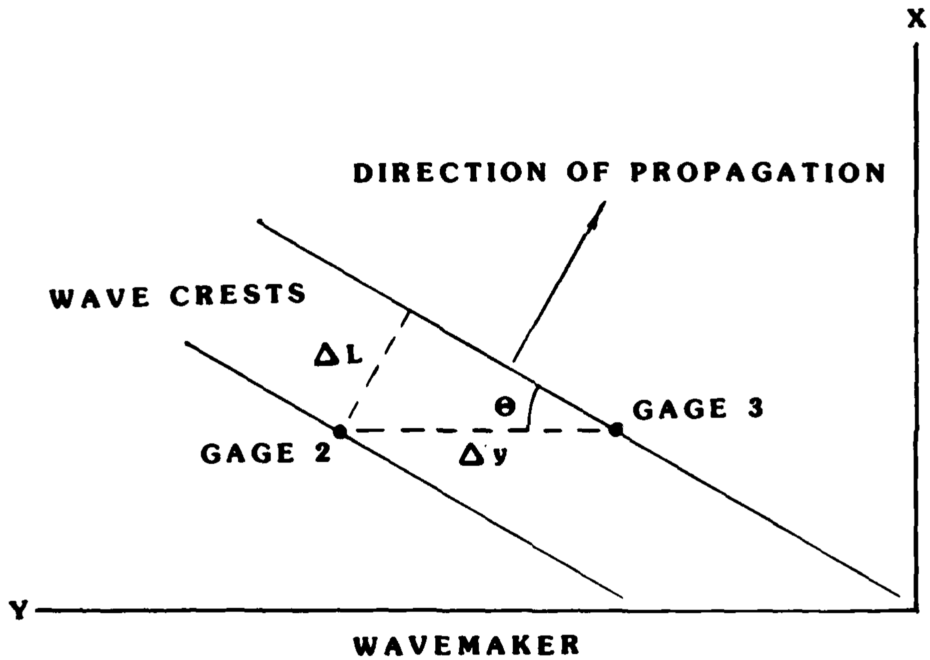


Figure 12. Calculation of wave direction angle

PART IV: TEST PROCEDURES

55. Descriptions of the test procedures are contained in five phases:

a. Theoretical predictions.

b. Control signal generation.

c. Wave gage calibration.

d. Wave generation and measurement.

e. Wave analysis.

Each of these is discussed in the paragraphs which follow.

Theoretical Predictions

56. In this initial phase, certain properties based on linear, depth-corrected, Airy wave theory were calculated for each of the 111 monochromatic waves desired. These properties were used in the design and planning of tests and generation of control signals. They are listed in Table 4 in groups according to their functions.

57. The computer program MONOSUMMARY was written to perform these calculations. It consists of a main driver program and 17 subroutines described in Table 5. The program hierarchy is straightforward: all subroutines are called from the main program in the order listed. The basic input parameters are water depth, wave period, generator stroke, and wave direction. Table 6 lists these and the other input variables required. An example of command procedure to run the program is contained in Appendix B. Descriptions of the output variables are given in Table 7. Finally, results from calculations for each of the 111 test cases are also contained in Appendix B.

Control Signal Generation

58. Either sinusoidal or cnoidal waveforms can be created in this phase. The program COMPONM can create one or more (maximum of 256) sinusoidal components which can be superimposed to obtain a desired monochromatic or spectral sea state. Program inputs include wave amplitude, period, direction, and phase (see Part III). Likewise, program COMPONC4 can create multiple cnoidal wave components. The user is prompted for desired wave height, wavelength (period), and water depth. The control signal can be started at the

origin or center of the generator. Each paddle is advanced in phase by a frequency increment corresponding to a 20-Hz D/A digitization rate. Thus, after completion of a cycle, the control signal automatically recycles. It can continue indefinitely until terminated by a control "C." The user then is prompted to close the file and tape with two end-of-file (EOF) marks. Appendix Tables C1 and C2 contain listings of the control files for programs COMPONM and COMPONC4, respectively. Also, Tables C1 and C2 summarize the operating procedure for each program, respectively.

Wave Gage Calibration

59. The process IDCAL is used to calibrate wave gages and ensure that proper gage potentiometer coefficients are used. It also contains descriptive information for documenting test output and data files for archives. Individual functions are organized in one of 15 headers which permit input of various parameters including number, name, coordinates, and relay numbers of the gages, potentiometer and rod coefficients, mean depth record, etc. Turner and Durham (1984), Briggs, Scheffner, and Hammock (1985), and Hampton (1986) describe these options in more detail. Prior to taking data, IDCAL is executed to place correct calibration coefficients in a generic file named "DUA1:[DATA_STO]FOR018.DAT". Whatever coefficients are in the input file specified are used unless the gages are recalibrated in this current run. These coefficients then are used in the analysis to convert measured voltages to inches. Appendix Table D1 describes the procedure for using IDCAL when calibration coefficients from a previous run are used. Table 8 lists the values used in header 2 for each of the five wave periods tested.

60. At the beginning and end of each day of testing, wave gages were calibrated according to the procedure described in Appendix Table D2. It is assumed that parameters specified in the other headers in process IDCAL have been previously specified. Wave gages are calibrated by physically moving gage sensor rods through a series of 11 steps to obtain calibration coefficients using a least-squares linear or quadratic fit. This averaging technique, using 21 voltage samples per gage, minimizes the effects of slack in gear drives and hysteresis in the sensors. Appendix Table D3 lists the quadratic fit, maximum deviation calibration coefficients (in units of feet times 10^{-5}) for each of the small gages for each day of testing. Also included are

the average, minimum, and maximum values. Appendix Table D4 contains corresponding values for Jordan wave gages on days when they were used.

61. The constancy of the 1-ft water depth was verified every day by taking a reading. A water level float and control valve were installed to maintain the depth within a tolerance of ±0.001 ft (0.012 in.) or 0.10 percent after 8 March. Prior to this date, the water level was manually checked and adjusted each day to within a tolerance of 0.03 in. or 0.25 percent. Constancy of water depth is necessary to ensure repeatability of test conditions.

Wave Generation and Measurement

62. This phase is controlled by one process called TAPEM2. Appendix E outlines the procedures and inputs required. This process allows the reading of a control signal from a 9T magnetic tape containing multiple files created in the control signal generation phase by program COMPONM or COMPONC4. TAPEM2 queries the user for the length of time to run a test and automatically turns off at the end of this time.

63. The length of time data is collected is determined by the user's response to the query for measurement delay time and the number of periods specified in Process IDCAL in Header 2. A 10-sec time period was allowed to elapse after starting of the test before activating the DSWG. This allowed time for the operator to turn on the DSWG if no assistance was available and to always begin at the same time for each test. For a 2-sec period, 6 cycles of data (12-sec total test duration) would be collected after the DSWG had been running for 16 sec. At the completion of data collection, the DSWG would continue running for 13 more seconds (i.e. 25 to 12 sec). Based on results from test cases, delay times, test lengths, and collection intervals shown in Table 9 for the five wave periods were used in all tests. Table 10 gives absolute times from start to finish for each wave period.

64. Prior to starting a test, gages were zeroed to within ±50 mv using the "Balance R" screw adjustments for each gage on the instrument console rack. The DSWG is activated by pressing the "Run" program button on the MTS system control panel of the wave generator control console.

65. During data collection it is important to prohibit input/output (I/O) from other users as this may interfere with accurate generation of waves and collection of data. If another user attempts an I/O operation (i.e.

logging on, editing, file manipulation, compiling, linking, or running a program, etc.) while a test is under way, the control signal to the DSWG is momentarily interrupted and subsequently accelerated to match the current signal position. The data collection might also be interrupted because the system resources are momentarily unavailable for data collection and processing. To prevent this, a warning message is sent to all on-line users prior to taking data to alert them that a test was about to begin. After completing a test, the "Stop" program button on the MTS system control panel is pressed and the "On Line" button on the tape drive activated for the next test. A message sent to all current users informs them that testing is completed and they may resume normal I/O operations until further notice.

Wave Analysis

66. After the data have been collected, analysis takes place in three stages. Stage 1 is a preprocessing stage in which the calibration coefficients and header information created by Process IDCAL (DUA1:[DATA_STO]FOR018.DAT) are combined with data collected by Process TAPEM2 (DLAO:[WAVE]ACCEPT.DAT) into one disk file in the directory DUA1:[DATA_ANAL]. Stage 2 is the zero-crossing analysis to calculate average and significant wave period and height for model and prototype (same as model in these tests) waves. A harmonic analysis to determine the percent of the total variance contained in a fundamental and the first three harmonics is calculated in the last stage. Command procedure files for each of these three stages are contained in Appendix F. Appendix F also describes the operating procedure for each stage.

PART V: TEST RESULTS AND ANALYSIS

67. In this part, results from measurements of wave profiles, periods, heights, and directions for both linear and nonlinear waves are presented and discussed.

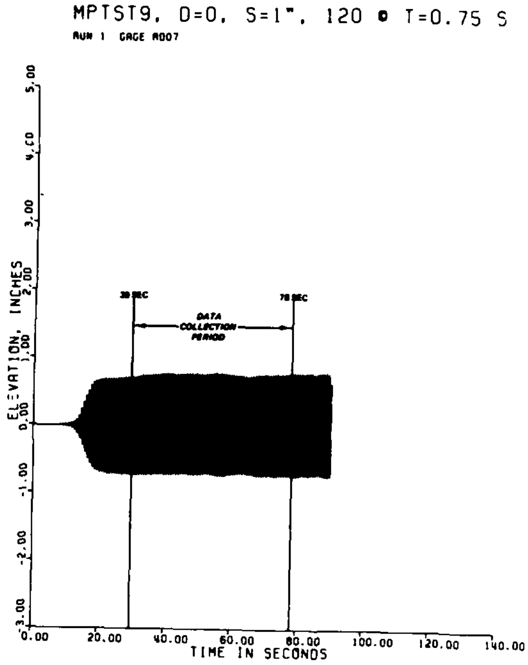
Test Case Results

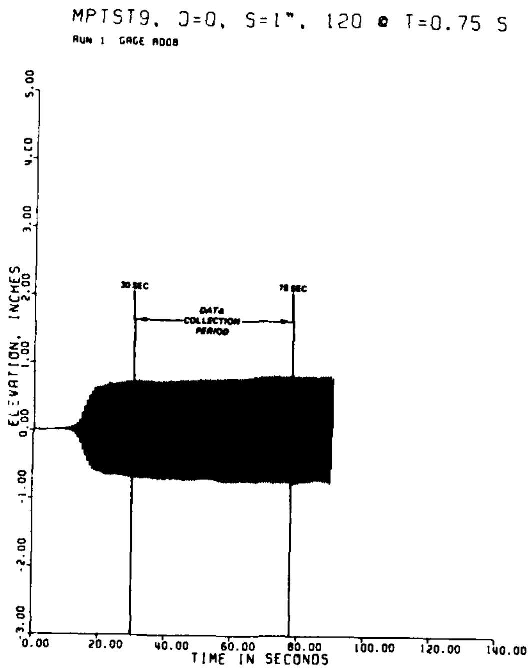
68. As discussed in Part III, a test case was run for each of the five wave periods to verify optimum times for collecting data. Table 11 summarizes these test case parameters and resulting data collection intervals selected. In all cases a stroke of 1 in. and a wave direction of 0 deg were used. Tests were run for a long duration to ascertain the degree of variation in wave profile with time. Travel times listed are theoretical times required for waves to travel from the DSWG to the back gage row (Time1) and to reflect off the beach and return to the back gages (Time2). (See Part III for detailed explanation of these terms.) Actual data collection intervals (repeated here for convenience from Tables 9 and 10) were determined based on a comparison of these values with wave profiles measured in the back gage row at X = 30 ft from the DSWG (i.e. gages 7, 8, and 9). For gages 7, 8, and 9 and wave periods of 0.75 and 1.50 sec, Figures 13a-c and 14a-c, respectively, are typical of the variations in wave profiles encountered. Each figure has a two-line descriptive title at the top for documentation purposes. The first line gives test case identification code, wave direction in degrees, DSWG stroke in inches, and number of cycles of the wave and its period in seconds. The second header line gives run number and gage number for the test. Note the increase in wave profile for the 1.50-sec wave period after approximately 60 sec elapsed time. This type of variation in wave profile (averaged for all three gages) was compared with the theoretically predicted times in determining optimum intervals for data collection.

Wave Profile Analysis

69. Representative surface elevation time series for each of the five wave periods 0.75, 1.00, 1.50, 2.00, and 3.00 sec at a fixed stroke of 1 in. and wave direction of 0 deg are shown in Figures 15a-e, respectively. The

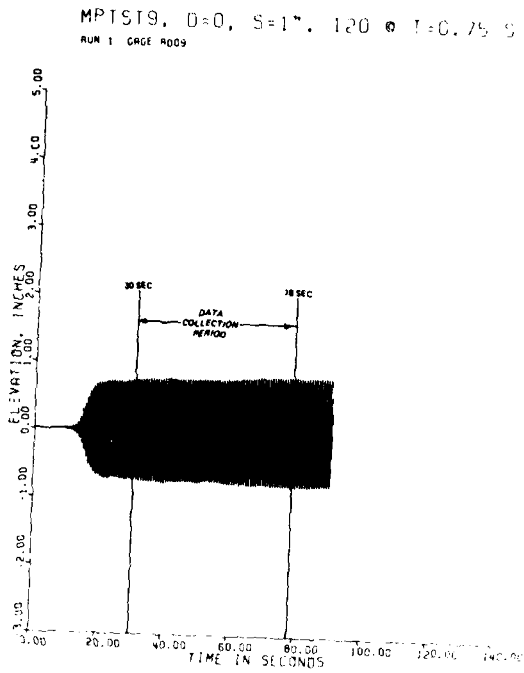
a. Gage 7





b. Gage 8

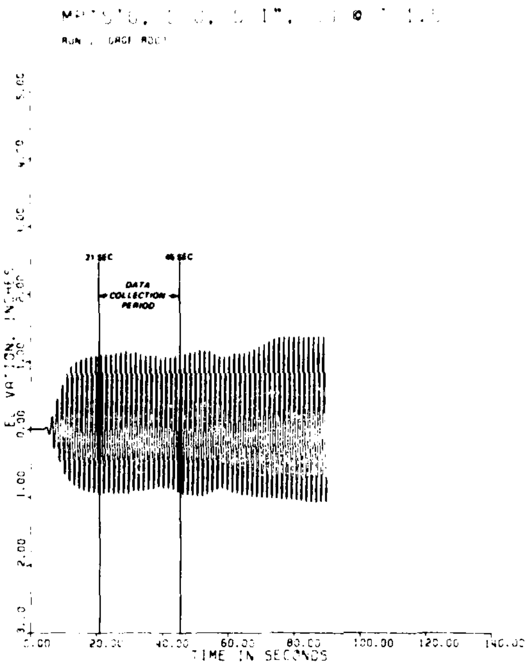
Figure 13. Test case wave profile, 0.75-sec period (Continued)



c. Gage 9

Figure 13. (Concluded)

a. Gage 7



b. Gage 8

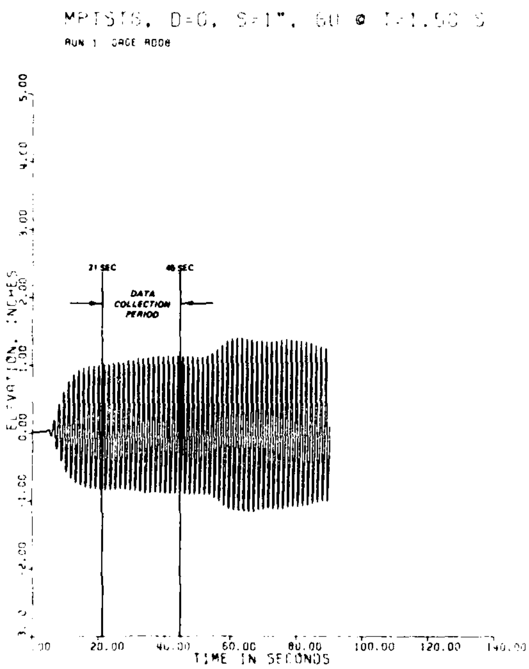
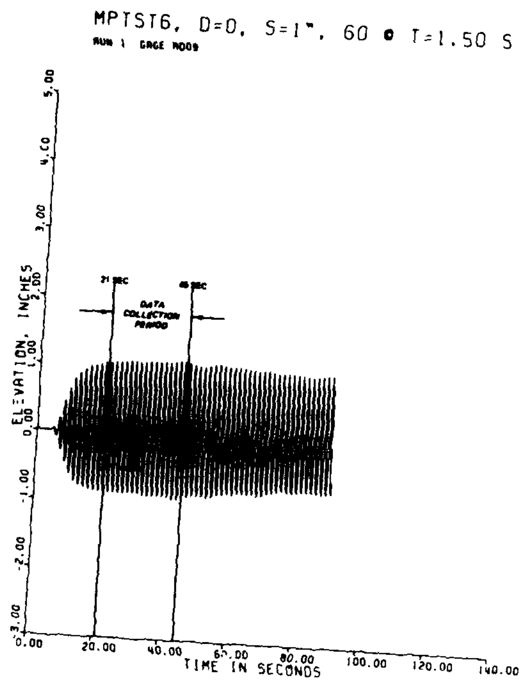


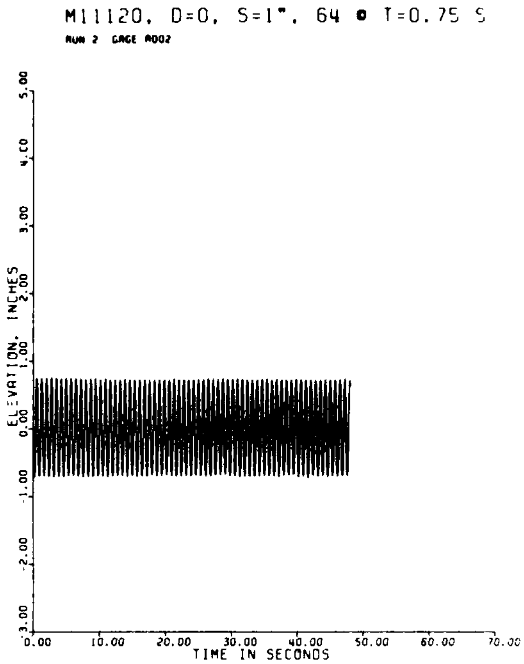
Figure 14. Test case wave profile, 1.50-sec period (Continued)

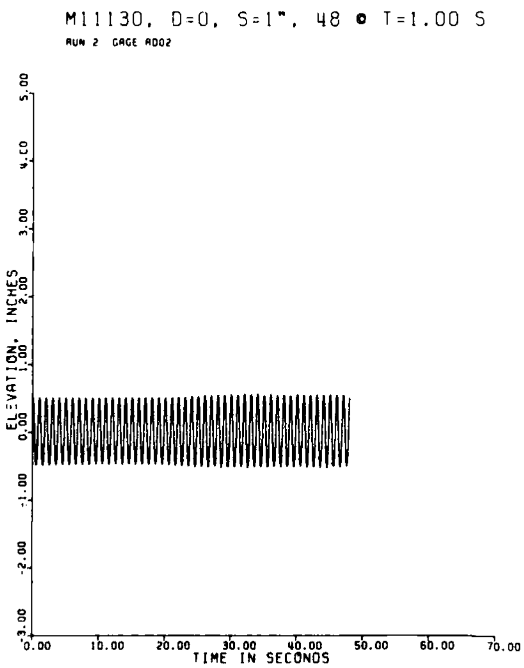


c. Gage 9

Figure 14. (Concluded)

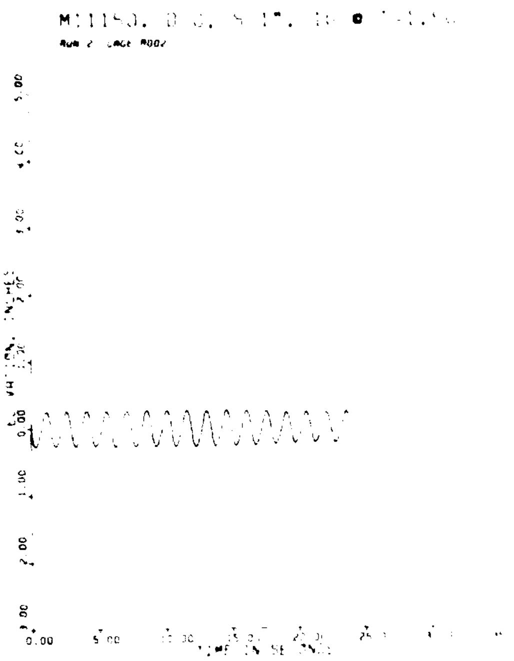
a. Waves of 0.75-sec period



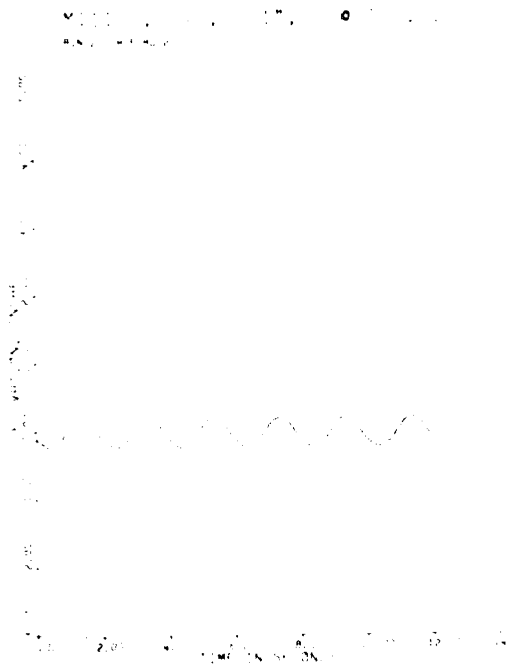


b. Waves of 1.00-sec period

Figure 15. Wave period profile (Sheet 1 of 3)

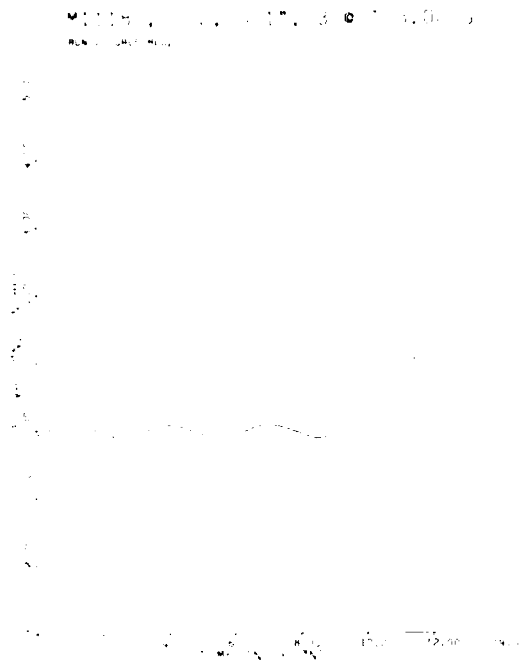


c. **Waves of 1.50-sec period**



d. **Waves of 2.00-sec period**

Figure 15. (Sheet 2 of 3)



e. Waves of 3.00-sec period

Figure 15. (Sheet 3 of 3)

measurement location was the center of the first row of the measurement area at coordinates X = 10 ft, Y = 45 ft (i.e. wave gage 2). The amount of variation in the wave profile with time is typical of that observed in most cases, with some gages exhibiting more and some gages less variation. The measured wave profiles are fairly linear for these low wave steepness and Goda's non-linear parameter (NLP) values. Figures 16a-e illustrate the variation of wave profile with strokes of 1, 3, 6, 9, and 11 in., respectively, for a fixed period of 3.00 sec and wave direction of 0 deg. The effect of increasing non-linearity due to the binding of a higher harmonic wave component for strokes greater than 3 in. is evident from these figures.

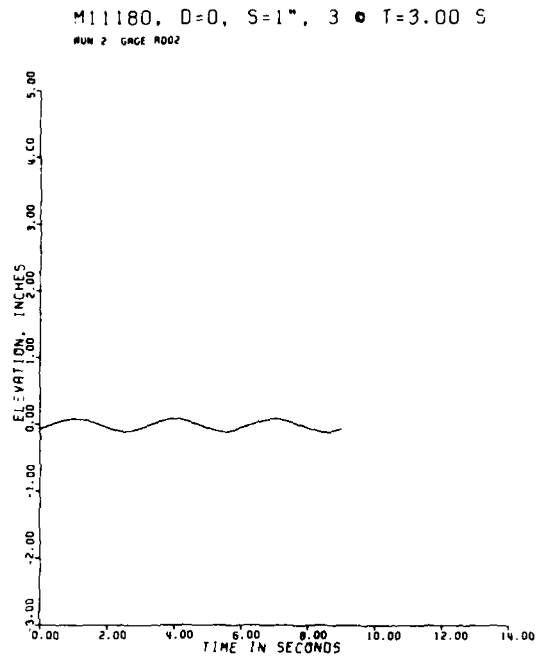
70. Finally, variation in wave profile with the five wave directions 0, 15, 30, 45, and 60 deg is illustrated in Figures 17a-e, respectively, for a fixed wave period of 1.50 sec and a stroke of 3 in. The increase in wave height with direction is clearly evident in these figures. Between 15 and 30 deg, the increase is not as drastic as in the other cases, however.

Wave Period Analysis

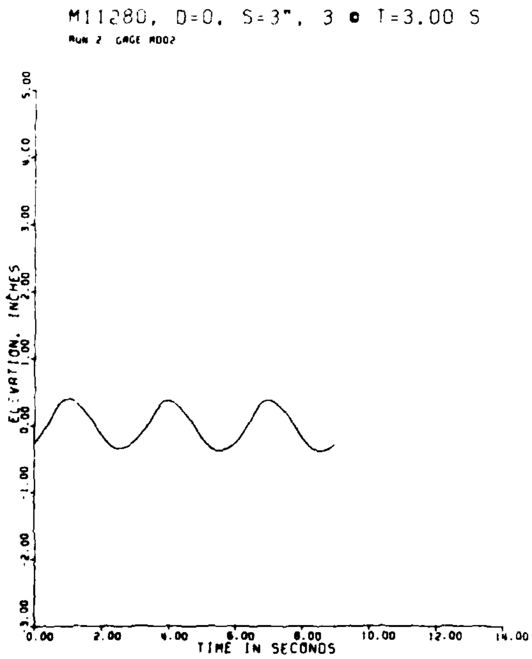
Zero-crossing analysis

71. Results of the zero-crossing wave period analysis for the linear wave cases are listed in Table 12 for wave directions 0, 15, 30, 45, and 60 deg. The measured wave period versus theoretical value is given for each of the five DSWG stroke wave conditions. Blank spaces in the tables for some wave conditions are due to the inability to generate a particular wave condition because of wave breaking. Measured average values are the average for each wave period over all strokes. The basin response factor (BRF) in the last column is a measure of the efficiency of the basin. It is the ratio of the measured average to the theoretical value in the first column. The BRF is also used in the paragraphs which follow to quantify the efficiency of the basin relative to wave height and wave direction. The overall BRF for all linear wave cases at 0 deg is 99.65 percent. Figure 18 shows measured versus theoretical wave periods corresponding to Table 12 for each of the five wave directions. The solid curve in each figure is for theoretical values and the symbols denote different wavemaker strokes. As can be seen from the plots and the BRF's, agreement is quite good.

72. Table 13 summarizes measured average wave periods from Table 11 for

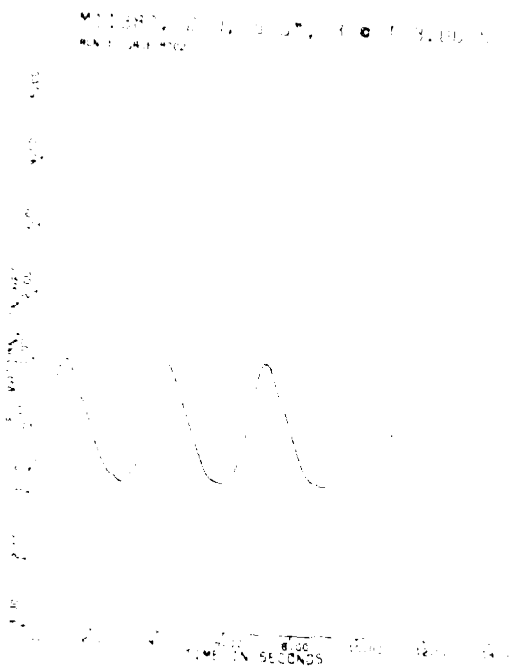


a. **Waves of 1-in. stroke**

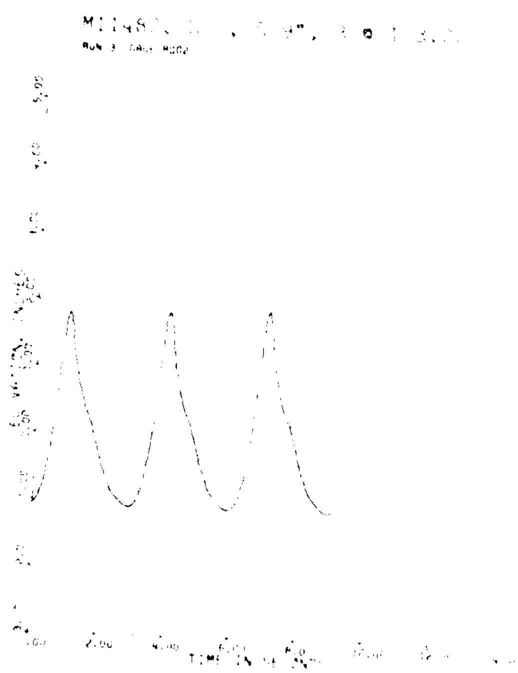


b. **Waves of 3-in. stroke**

Figure 16. Wave profile with strokes (Sheet 1 of 3)

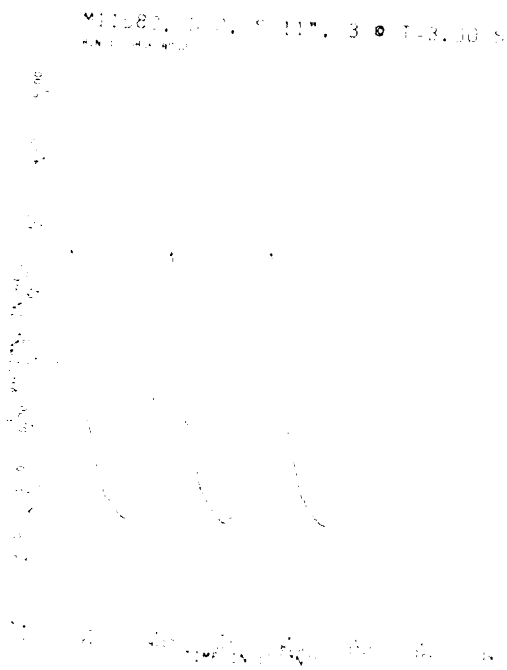


c. Waves of 6-in. stroke



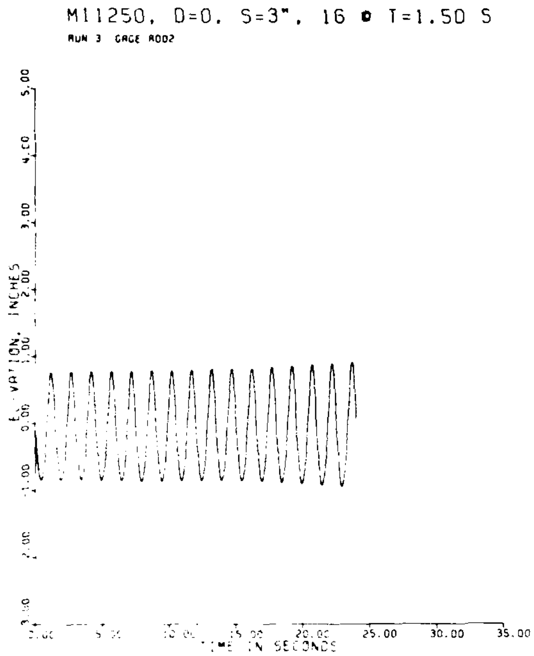
d. Waves of 9-in. stroke

Figure 16. (Sheet 2 of 3)

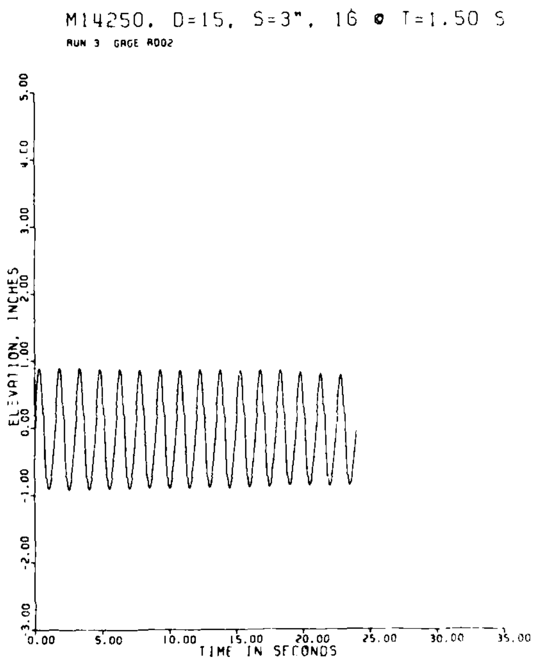


e. Waves of 11-in. stroke

Figure 16. (Sheet 3 of 3)



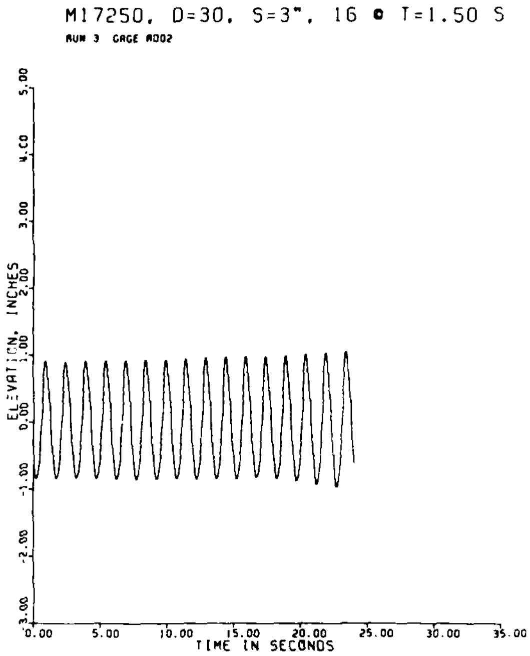
a. Waves of 0-deg wave direction

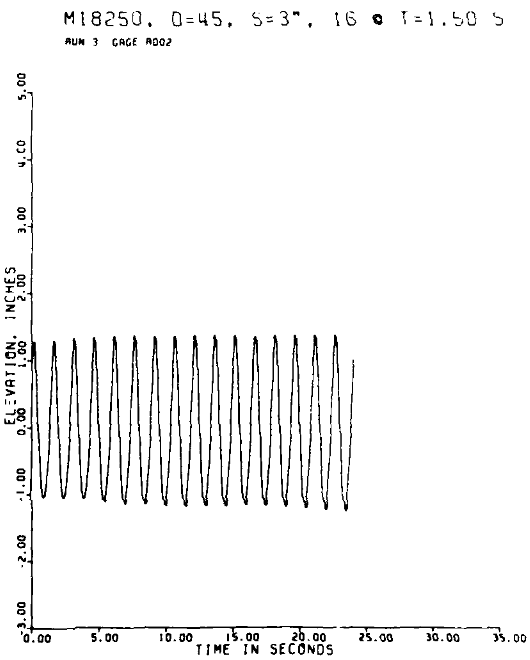


b. Waves of 15-deg wave direction

Figure 17. Wave profile with direction (Sheet 1 of 3)

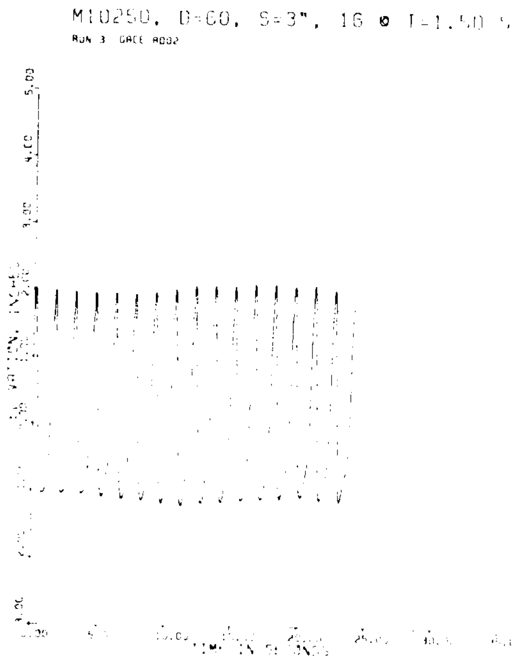
c. Waves of 30-deg wave direction





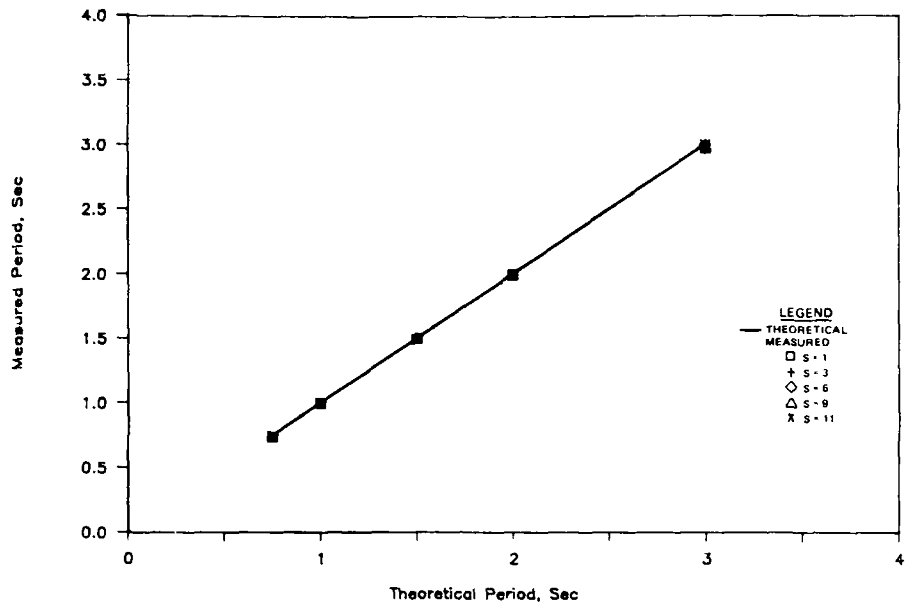
d. Waves of 45-deg wave direction

Figure 17. (Sheet 2 of 3)

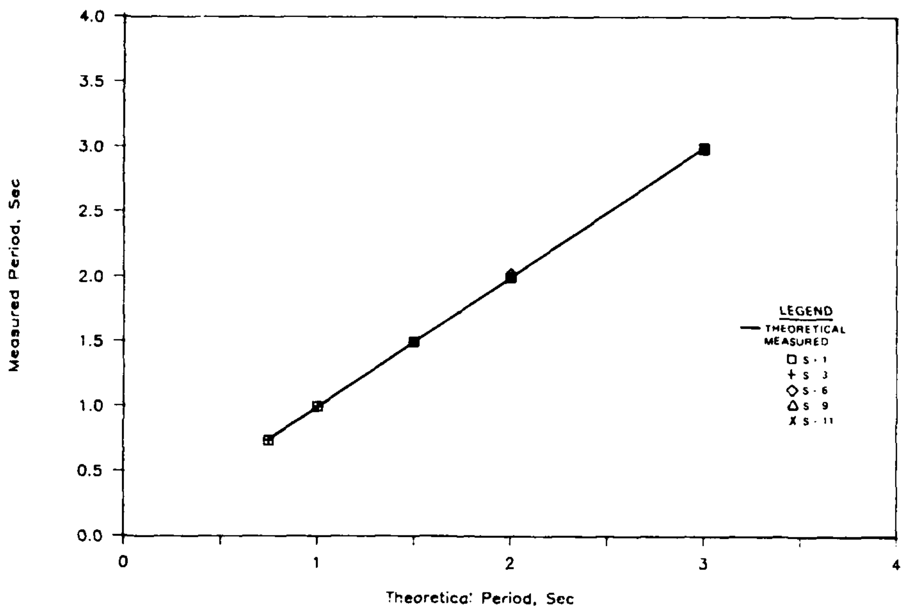


e. **Waves of 60-deg wave direction**

Figure 17. (Sheet 3 of 3)

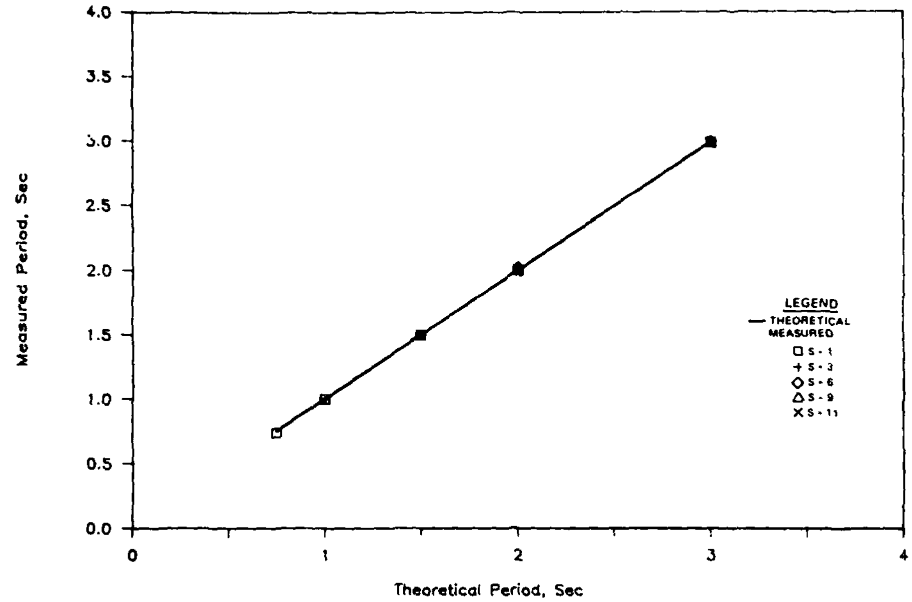


a. Waves of 0 deg

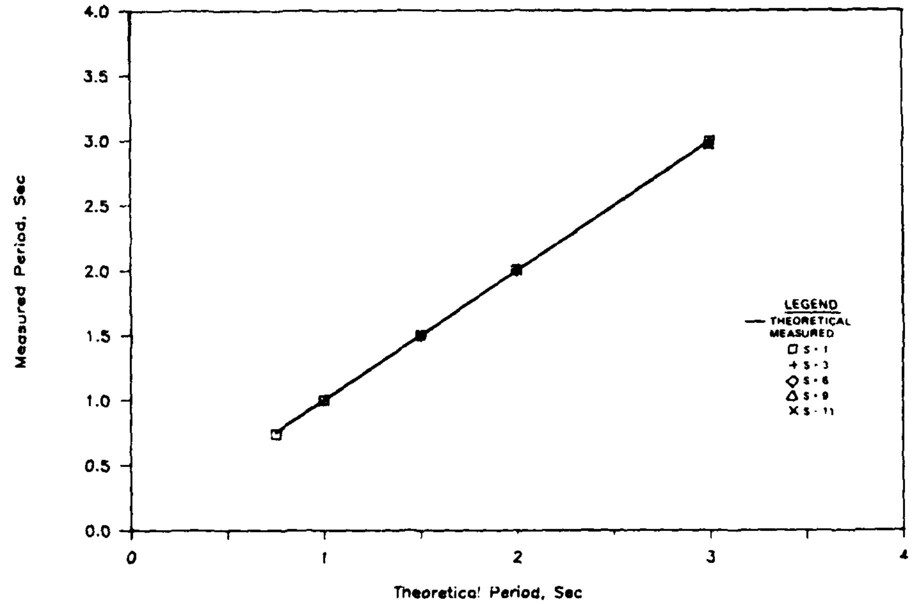


b. Waves of 15 deg

Figure 18. Measured versus theoretical wave periods, depth = 1 ft (Sheet 1 of 3)

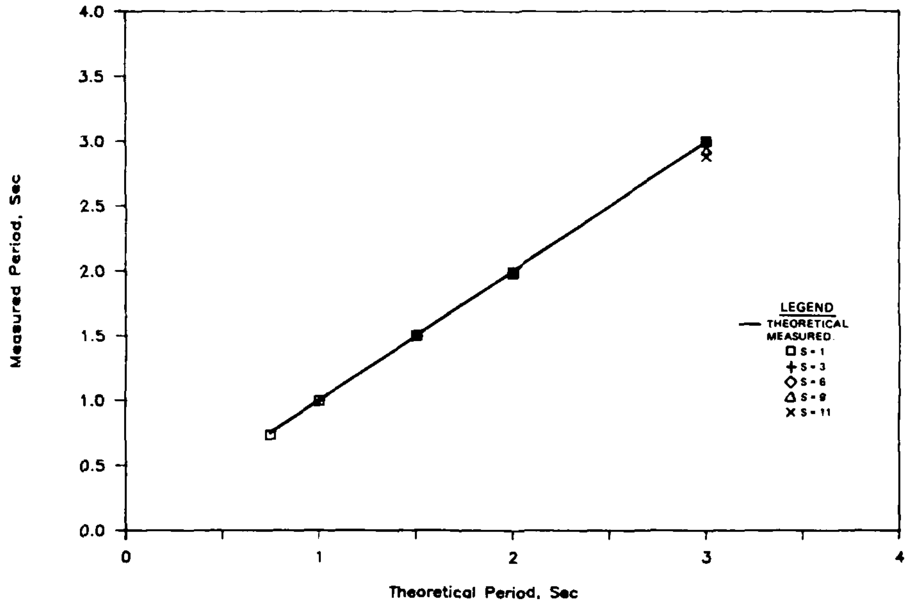


c. Waves of 30 deg



d. Waves of 45 deg

Figure 18. (Sheet 2 of 3)



e. Waves of 60 deg

Figure 18. (Sheet 3 of 3)

each of the five wave directions. An overall average and BRF are listed in the last two columns. Figure 19 illustrates excellent agreement between measured and theoretical values corresponding to an average BRF of 99.6 percent for all strokes and directions.

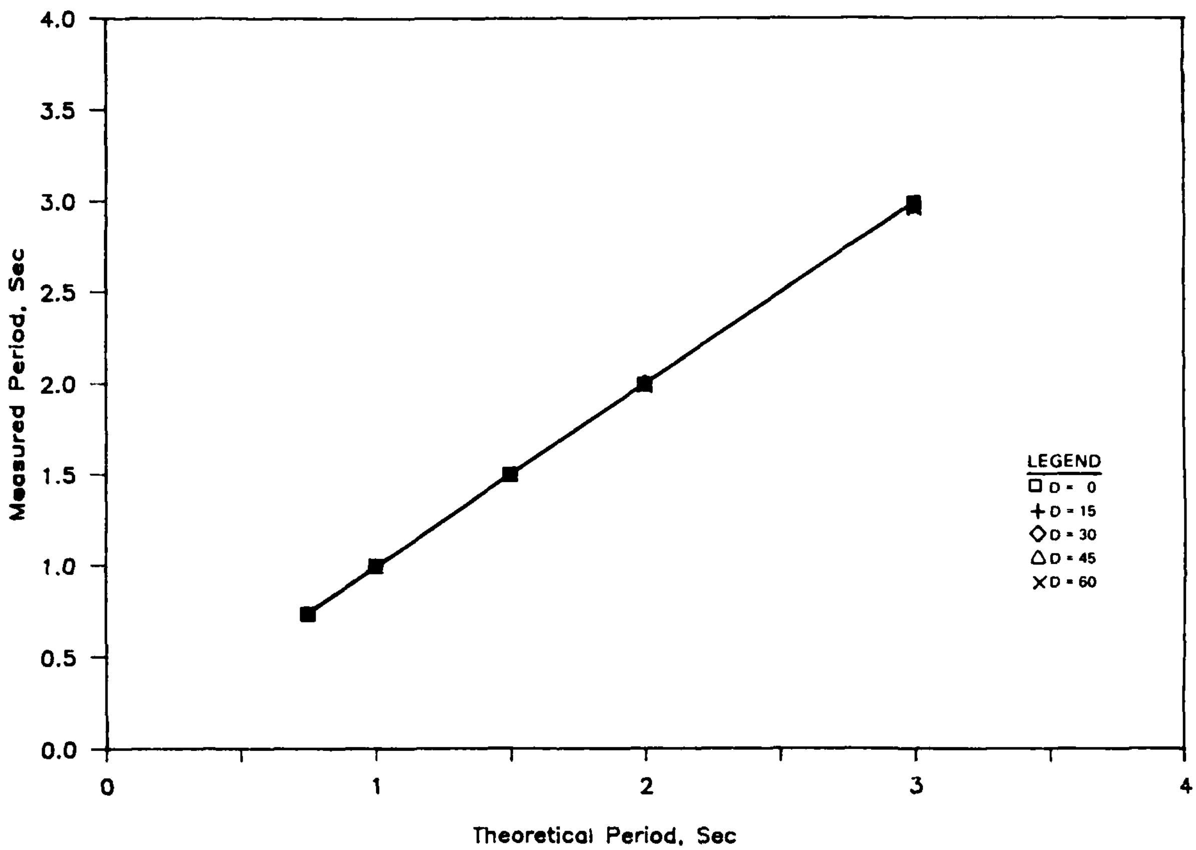


Figure 19. Measured average versus theoretical wave period for all directions, depth = 1 ft

Harmonic analysis

73. As discussed previously in Part III, a least-squares harmonic analysis was performed on the linear wave data to quantify variance contained in the fundamental and first three harmonics. Table 14 lists percent variance or total energy contained in the first harmonic for each of the five wave directions 0, 15, 30, 45, and 60 deg. In addition to percent variance, Goda's NLP Π is given for the five DSWG stroke and wave period combinations for each wave direction. The variation of total energy with this nondimensional parameter is shown in Figure 20 for all five wave directions. Wave conditions with

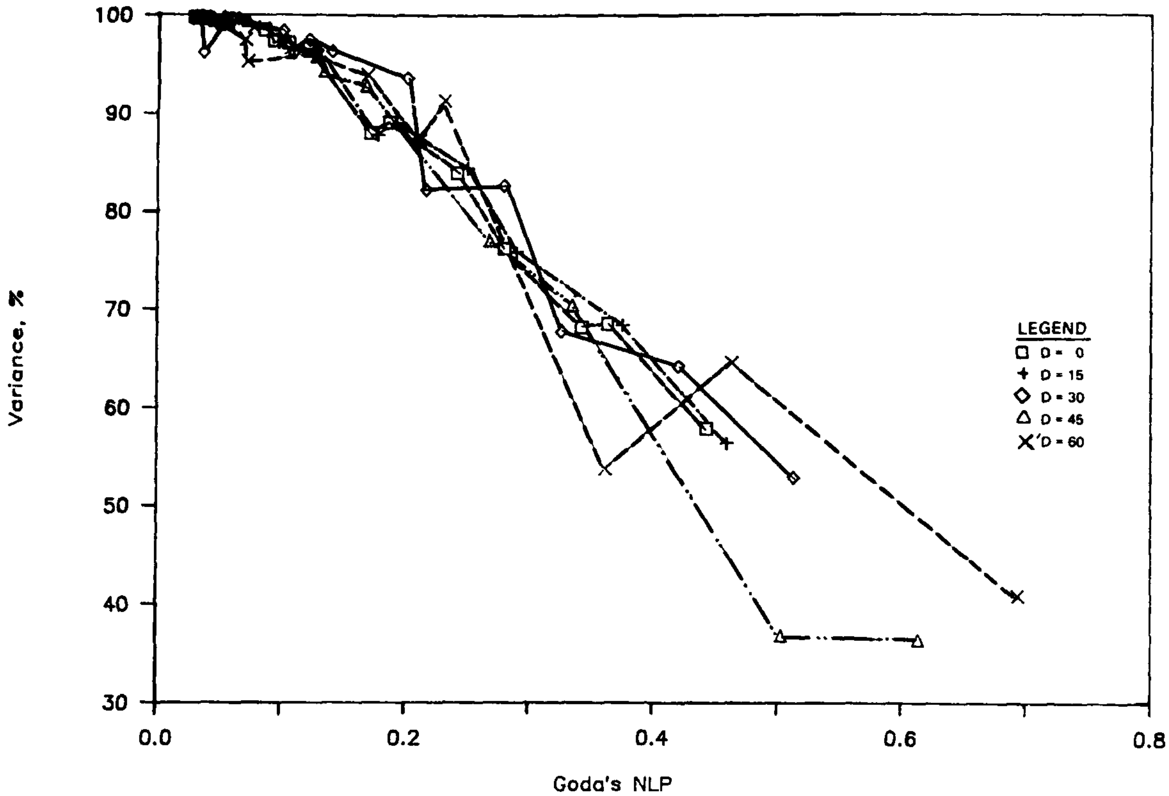


Figure 20. Harmonic analysis of linear waves

Π values less than 0.2 have approximately 85 percent or more of their total energy in the first harmonic. This indicates a reasonably linear or sinusoidal wave profile.

Wave Height Analysis

Zero-crossing analysis

74. Results of the zero-crossing wave height analysis for linear wave cases are listed in Table 15 for the five wave directions 0, 15, 30, 45, and 60 deg. In the table measured wave height is compared with the theoretical value (see Part III) for each wave period and stroke combination. The value of maximum possible wave height (i.e. prebreaking wave height) for each wave period is repeated for reference in the second column of each table. Maximum measured values are discussed in paragraph 77. Again, blank spaces in the measured columns are because it is not possible to generate waves with these conditions without breaking occurring. As explained in Part III, the effect

of directionality on wave height is to increase its value relative to the two-dimensional height of a wave traveling perpendicular to the DSWG (i.e. 0-deg wave direction). Thus, as the wave direction increases, the number of waves which can be generated tend to decrease in "stairstep" fashion as the wave period and stroke increase.

75. Plots of the measured versus theoretical wave heights for each of the five strokes tested are shown in Figure 21 for wave directions corresponding to Table 14. The solid curves in each figure represent theoretical values and the symbols denote different wavemaker strokes. The top curve in each section of the figure is the "breaking wave limit curve," based on Equation 5. The theoretical curves were plotted from calculations based on only the five discrete wave periods tested. Thus, they are not as smooth as they would have been had they been plotted using a continuous wave period array.

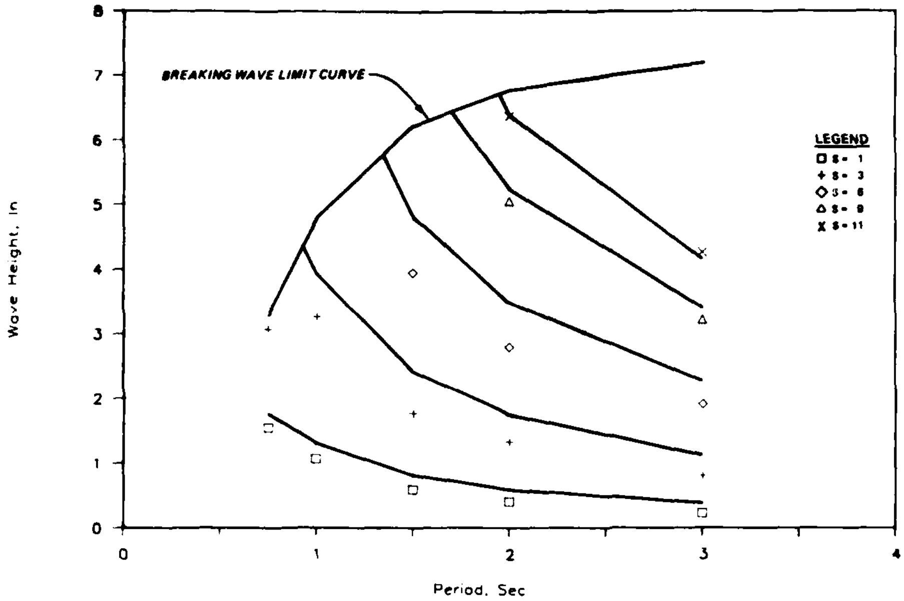
76. From the table and plots, it is evident that linear wave theory usually overpredicts wave height for the DSWG basin. The only exception appears to be the 3-sec period, 11-in. stroke combination for wave directions less than 30 deg. The average BRF (see paragraph 71) for all period and stroke combinations at 0 deg is 87.7 percent. The average BRF over all wave cases is 79.2 percent. The general trend is for the BRF to increase with increasing stroke for a fixed wave direction and to decrease with wave direction for all stroke combinations.

Wave breaking tests

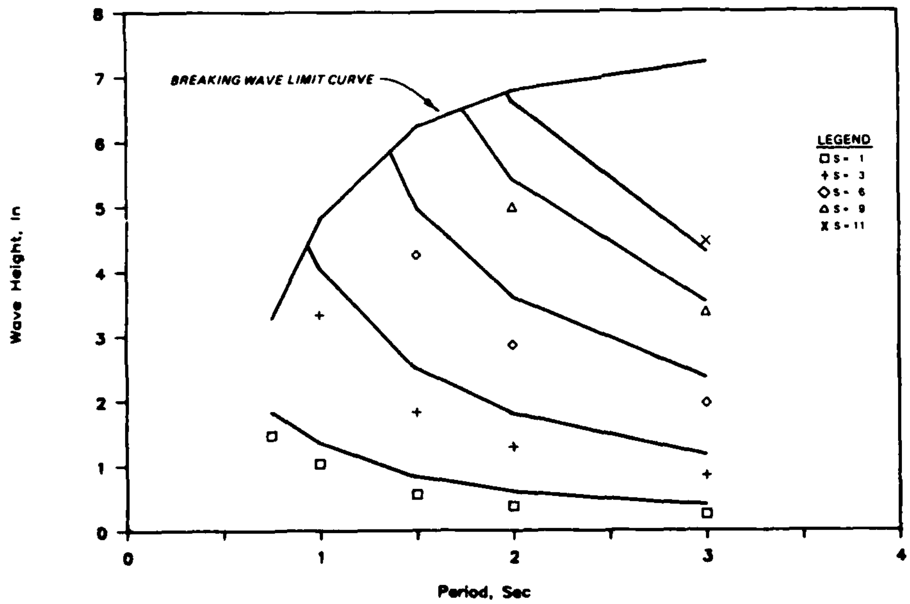
77. To verify maximum possible wave heights, a series of three waves was run for each wave period to bracket the breaking phenomenon. All tests were run at a wave direction of 0 deg. Table 16 and Figure 22 illustrate the results from this series of tests. The results are in agreement with those reported previously; namely, the wave heights are slightly overpredicted for the DSWG basin. Measured wave heights near breaking always occurred below predicted values, especially for wave periods greater than 1.5 sec. Required strokes always were larger than predicted theoretical values. For the 3-sec wave period, it was not possible to determine the accuracy of linear theory because a stroke larger than the maximum DSWG stroke of 12 in. is required.

Constancy of wave height

78. To evaluate constancy of wave height within the measurement area, the measured wave height at each of the nine gages was examined for linear control signals with strokes of 3 in., periods of 1.00 and 1.50 sec, and wave

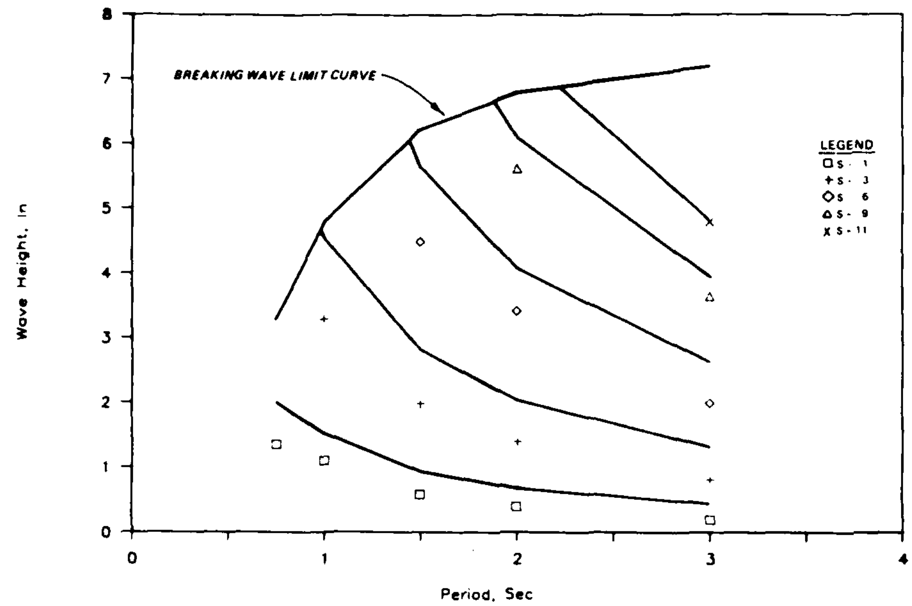


a. Waves of 0 deg

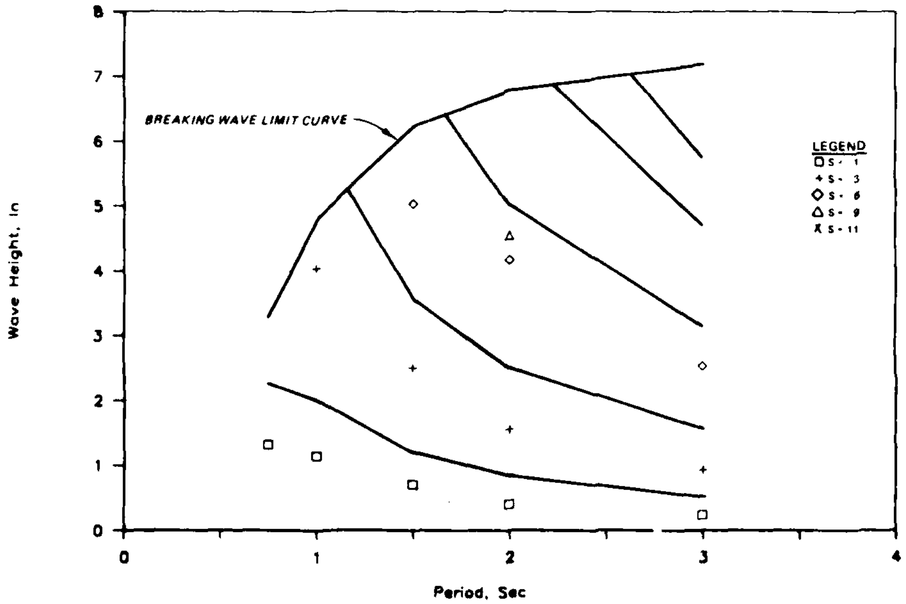


b. Waves of 15 deg

Figure 21. Measured versus theoretical wave heights, depth = 1 ft (Sheet 1 of 3)

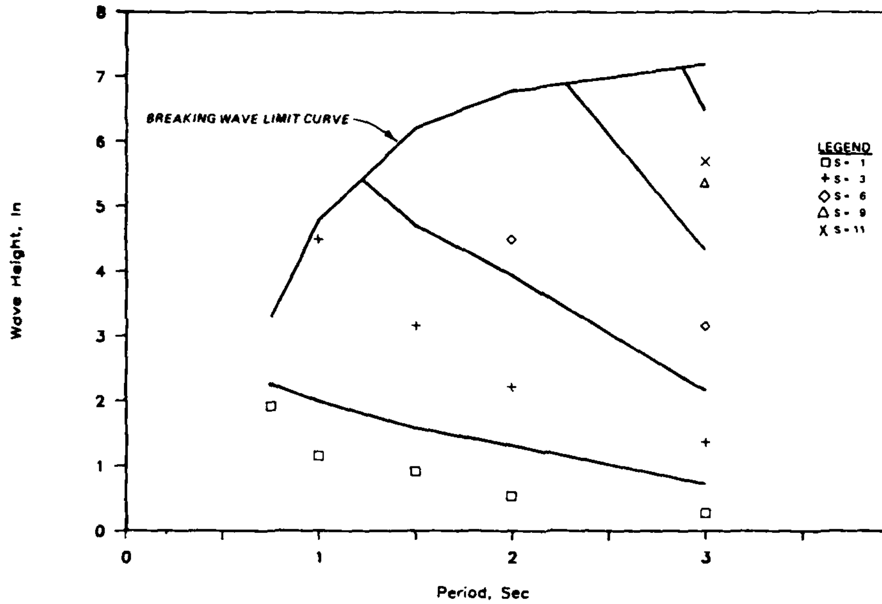


c. Waves of 30 deg



d. Waves of 45 deg

Figure 21. (Sheet 2 of 3)



e. Waves of 60 deg

Figure 21. (Sheet 3 of 3)

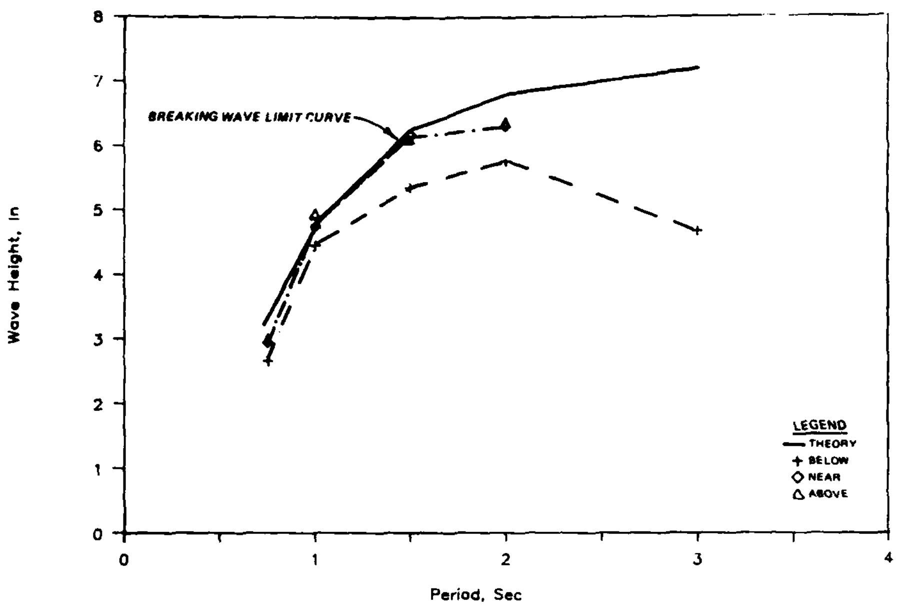
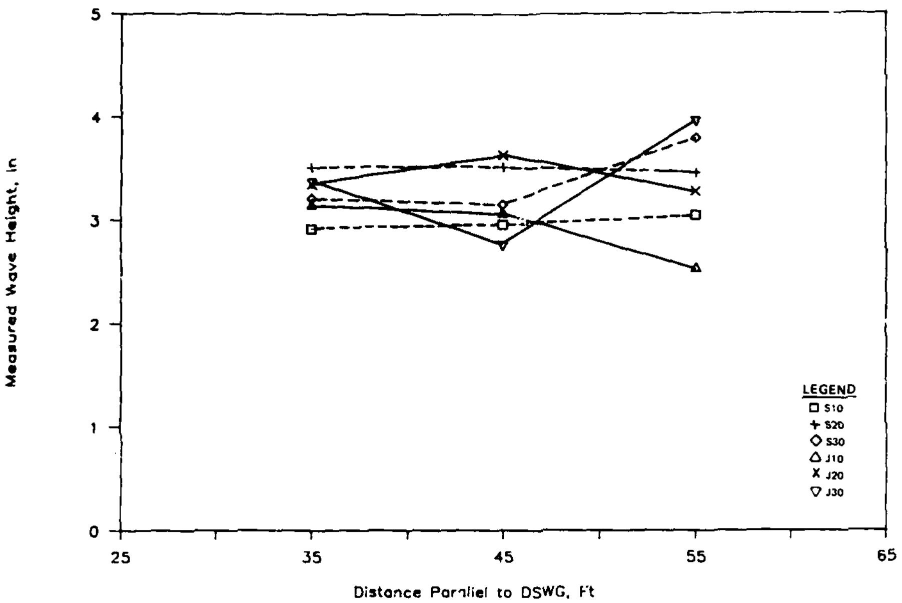


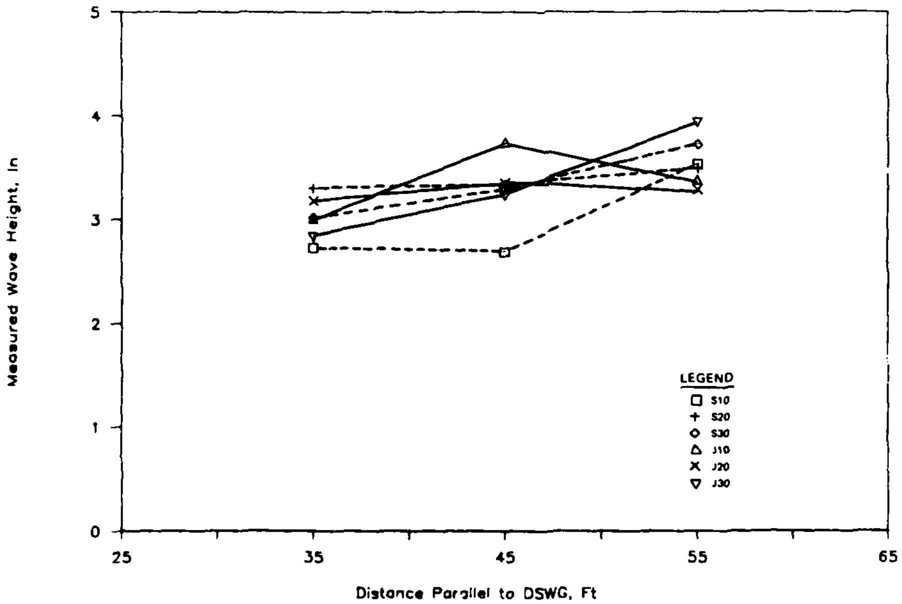
Figure 22. Wave breaking tests

directions of 0, 15, 30, and 45 deg. Table 17 lists the theoretical (based on the three-dimensional height-to-stroke H/S ratio), measured, average $\overline{H}$, and mean variation wave height $\Delta\overline{H}$ for each of the eight cases for both small and Jordan wave gages. The purpose of the gage comparisons is to quantify what effect, if any, the higher resolution of the small gages has on the measured values. Corresponding measured wave heights with a period of 1.00 sec for both small and Jordan wave gages are plotted in Figure 23 for wave directions 0, 15, 30, and 45 deg. Similarly, the cases with a period of 1.5 sec are shown in Figure 24 for their wave directions. The data for the small wave gages are shown with a dashed line and that of the larger range Jordan wave gages with a solid curve.

79. Although some measured wave heights appear to vary significantly among gages, $\Delta\overline{H}$ calculated for the array of nine gages was always within tolerance limits suggested by Sand (1979). (See Part III.) These values followed the same pattern he observed of increasing with increasing wave direction. The one exception was for 30 deg, where $\Delta\overline{H}$ seemed to dip slightly in all cases except for the 1.00-sec Jordan gages. The 1.50-sec wave periods seemed to give less wave height variation than corresponding 1.00-sec wave periods, except for a wave direction of 45 deg. For the 1.00-sec waves, there there is a large scatter of measured points about the center line of the measurement area for different directions.

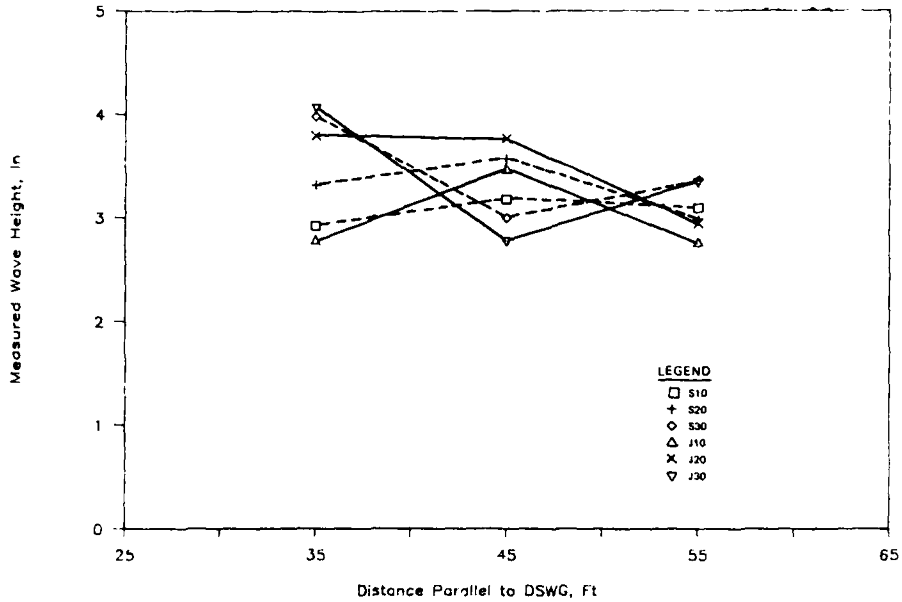


a. Waves of 1.00 sec and 0 deg

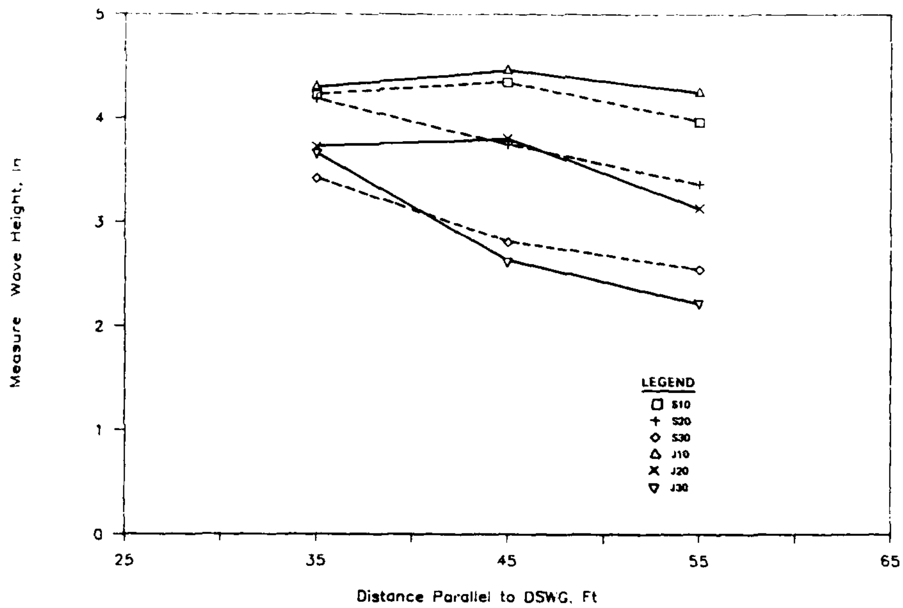


b. Waves of 1.00 sec and 15 deg

Figure 23. Constancy of wave heights (S10 means small gage, X = 10 ft; J10 means Jordan gage, X = 10 ft, etc.) (Continued)

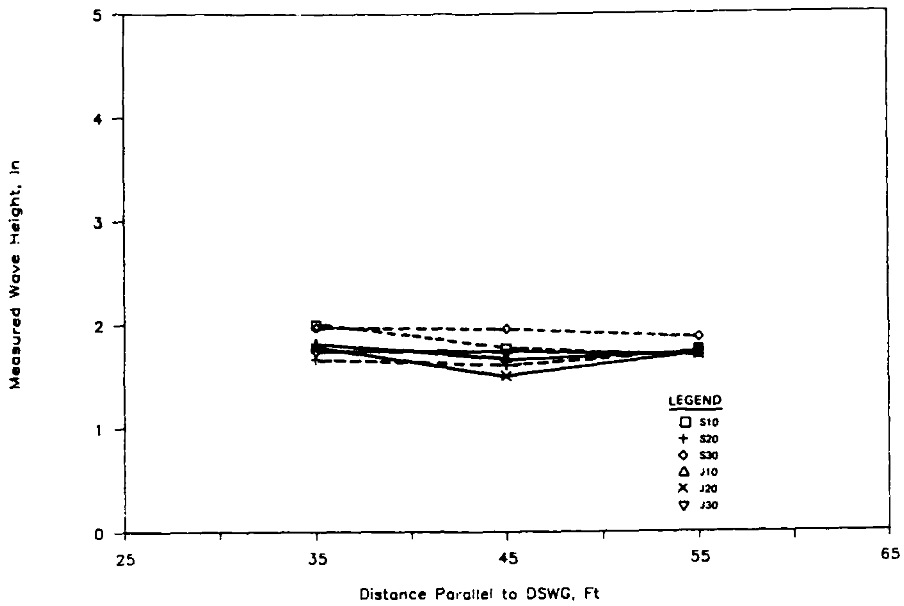


c. Waves of 1.00 sec and 30 deg

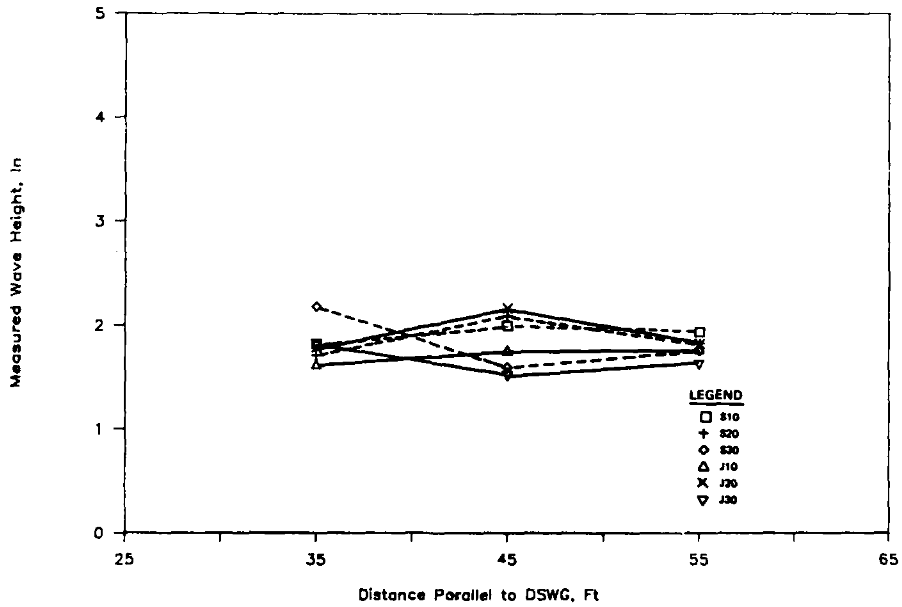


d. Waves of 1.00 sec and 45 deg

Figure 23. (Concluded)

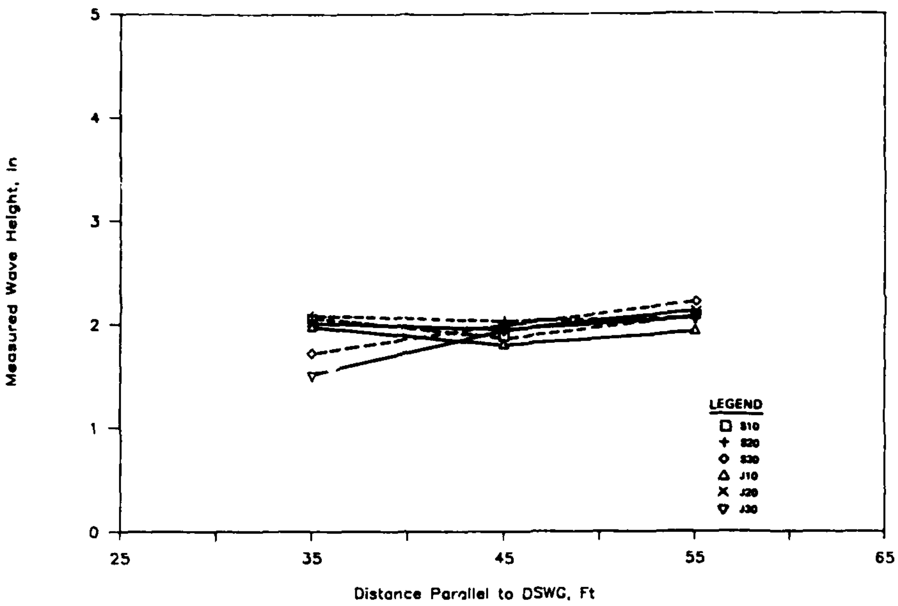


a. Waves of 1.50 sec and 0 deg

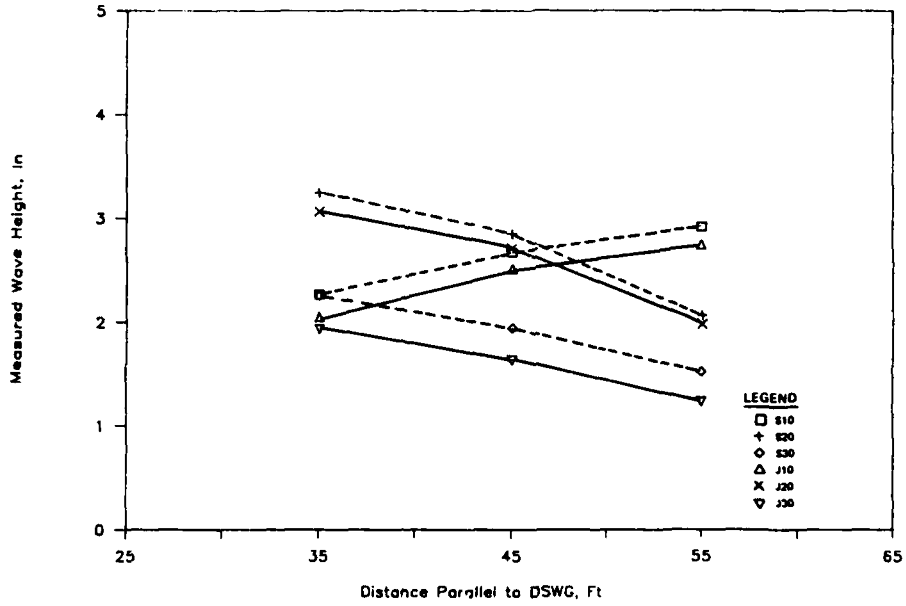


b. Waves of 1.50 sec and 15 deg

Figure 24. Constancy of wave heights (Continued)



c. Waves of 1.50 sec and 30 deg



d. Waves of 1.50 sec and 45 deg

Figure 24. (Concluded)

80. To ascertain repeatability, the tests were run twice for small gages at a wave direction of 0 deg. Measured wave heights for each gage were very consistent, differing no more than 0.5 percent in $\Delta\overline{H}$ between runs.

81. The major cause of variation is probably higher harmonics (especially free second) and wave reflections within the asymmetric basin. Wave absorption characteristics of the basin, as described in Part II, are quite reasonable. The combination of all sources of variability, as described in Part III, contributes to overall measured wave height variability.

82. An additional explanation of some observed variation is the tolerance on wave gage calibrations. The maximum deviation of each wave gage at any one step in the 11-step calibration process is a good indicator of this tolerance (see Appendix Tables D3 and D4). The average values of maximum deviation for small and Jordan gages are 0.015 in. (0.47 percent of full scale of 3.25 in.) and 0.145 in. (1.45 percent of full scale of 10 in.), respectively. The Jordan gages' maximum deviation values are approximately 10 times larger than those for the small gages. Relative to full scale of calibration, the difference between the two is only about three times for the Jordan gage.

Wave Direction Analysis

Integer paddle assumption

83. As explained in Part III, an integer number of paddles was used to determine wave directions in the control signal. Thus, except for the wave direction of 0 deg, measured wave directions do not match desired wave directions of 15, 30, 45, and 60 deg exactly but are reasonably close. Measured wave directions are compared with input wave directions rather than with desired wave direction. The amount of variation increases for directions greater than 30 deg and wave periods less than 1 sec. The average BRF (see paragraph 71) for the wave direction of 0 deg is 99.9 percent. The overall BRF for all directions, strokes, and period combinations was 98.81 percent, indicating a high probability of generating a wave with the desired wave direction.

84. Table 18 lists measured versus theoretical wave directions for the five desired wave directions 0, 15, 30, 45, and 60 deg. The format of this table is similar to that for periods and wave heights presented earlier.

Figure 25 (corresponding to Table 18) illustrates these relationships versus wave period for each desired wave direction.

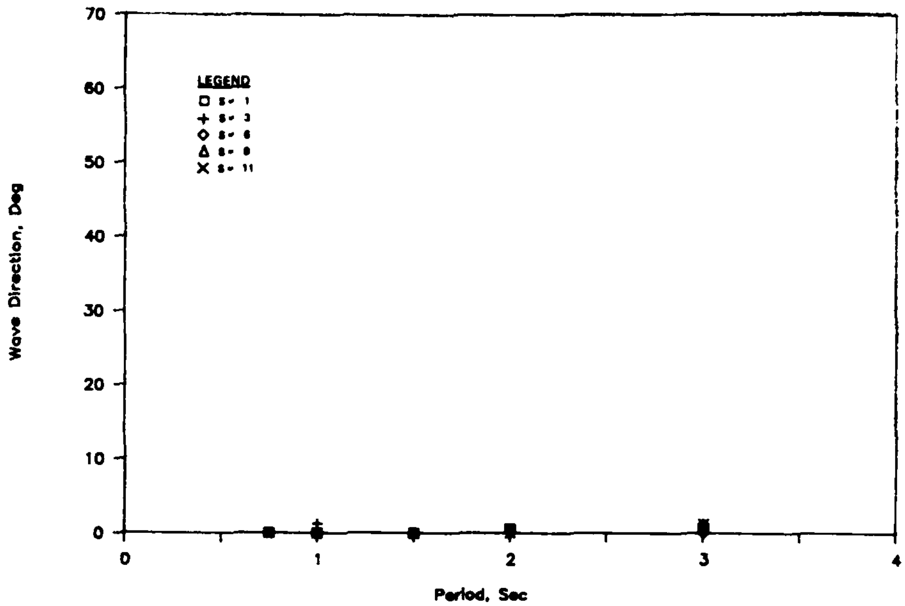
85. Table 19 lists measured average values (eighth column from Table 18) for each desired wave direction versus wave period. The maximum wave direction obtainable with an integer number of paddles for each wave period is repeated in the second and third column (see Part III). Finally, the excellent agreement between measured and theoretical wave directions is plotted in Figure 26. The solid lines are theoretical values, and symbols denote the average for each direction over all period and stoke combinations. Again, the top curve is the breaking wave limit curve from Equation 5. The worst fit is for the 3-sec wave period at 60 deg where the average BFR is 95.1 percent.

Exact paddle assumption

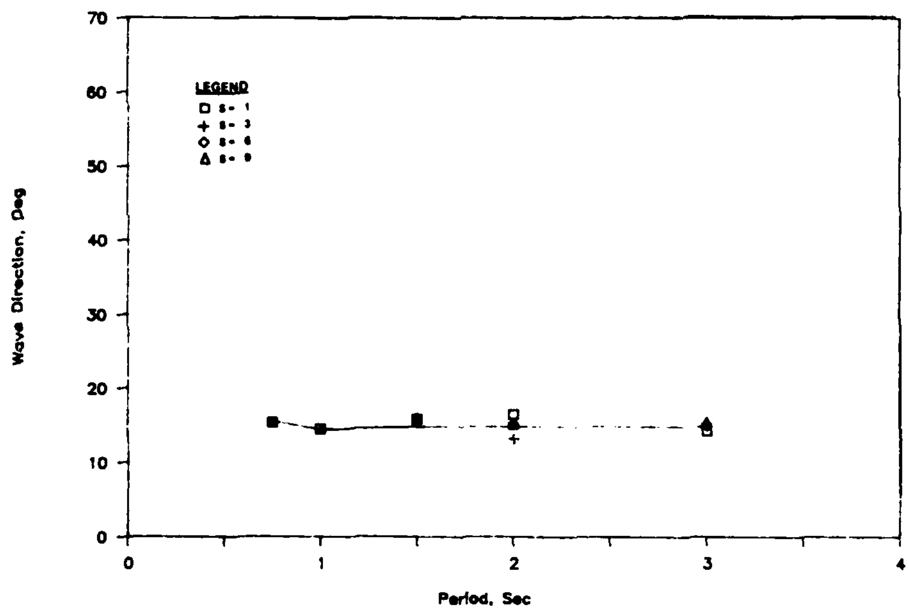
86. In order to verify the ability of the DSWG to generate wave directions requiring a noninteger number of paddles, a series of three tests was run with a fixed wave period of 1.5 sec and a desired wave angle of approximately 60 deg. The second test was identical to the case with an integer number of paddles. The other two cases were designed to bracket the desired value (i.e. 60 deg) with a noninteger number of paddles to generate waves with directions above and below 60 deg. Based on the values measured and the BRF's calculated (Table 20), wave directions near ±90 deg can be generated at any wave period, provided more than two paddles are used. For wave periods less than 1 sec, however, the ability to generate waves near ±90 deg is somewhat limited since less than three paddles are required. As pointed out in Part III, a more reasonable upper limit on 0.75-sec waves is 70 deg.

Nonlinearity Effects

87. To ascertain the importance of nonlinear, second-order control theory, a series of 16 cnoidal waves was created and tested in the DSWG basin. These waves consisted of combinations of three periods at 1.5, 2.0, and 3.0 sec and three generator strokes of 6, 9, and 11 in. for each of two wave directions of 0 and 30 deg. It is not possible to generate a cnoidal wave with a 3-sec period and 11-in. stroke in a water depth of 1 ft. The control and feedback signals were monitored to verify accuracy of the control signal in form, period, and amplitude.

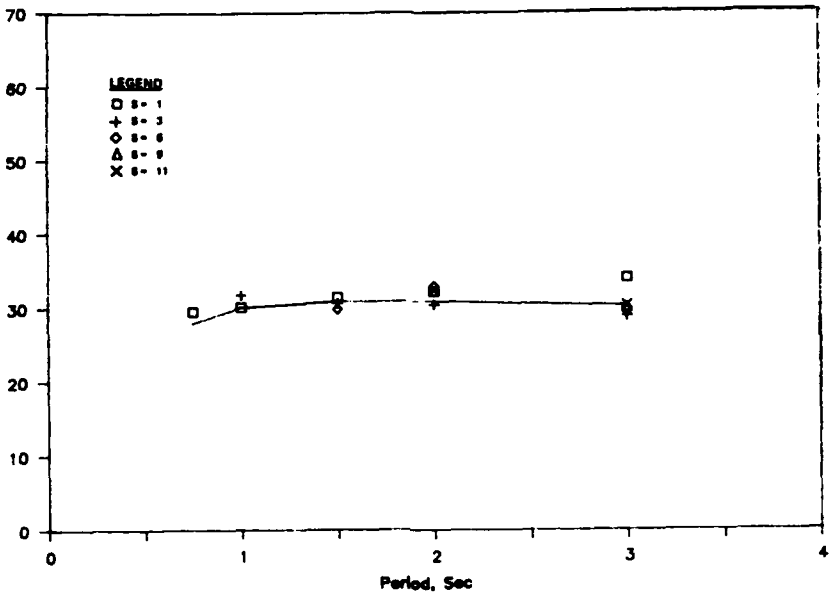


a. Waves of 0 deg

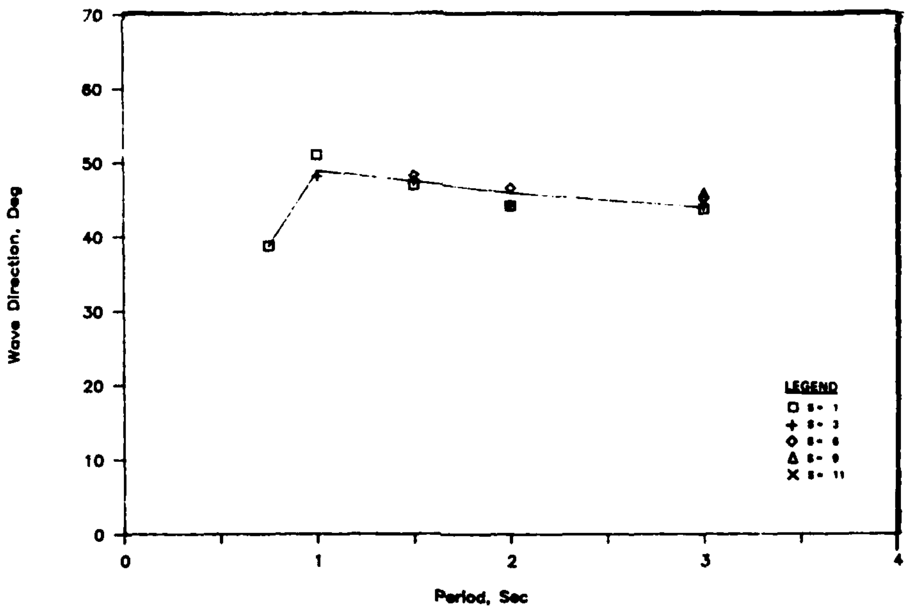


b. Waves of 15 deg

Figure 25. Measured versus theoretical wave directions, depth = 1 ft (Sheet 1 of 3)

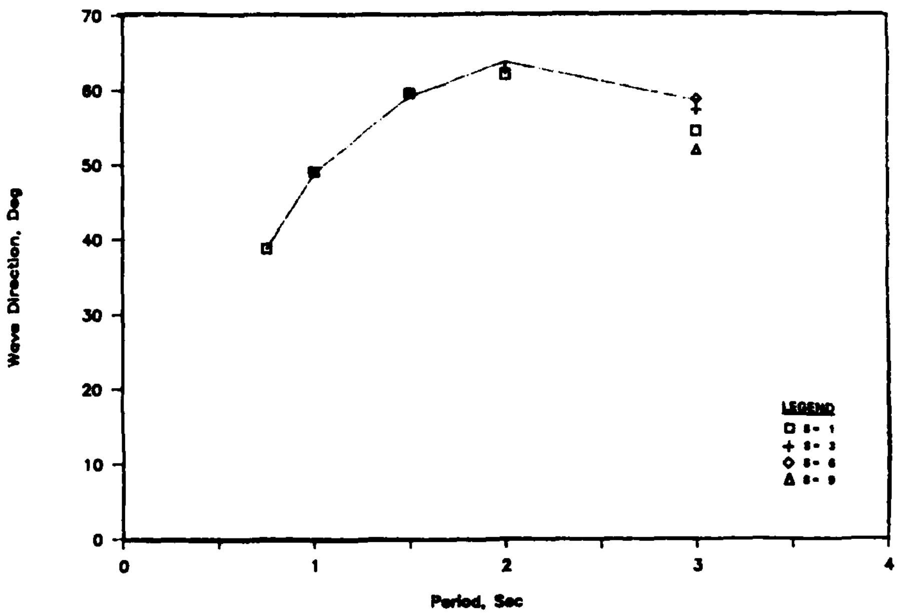


c. Waves of 30 deg



d. Waves of 45 deg

Figure 25. (Sheet 2 of 3)



e. Waves of 60 deg

Figure 25. (Sheet 3 of 3)

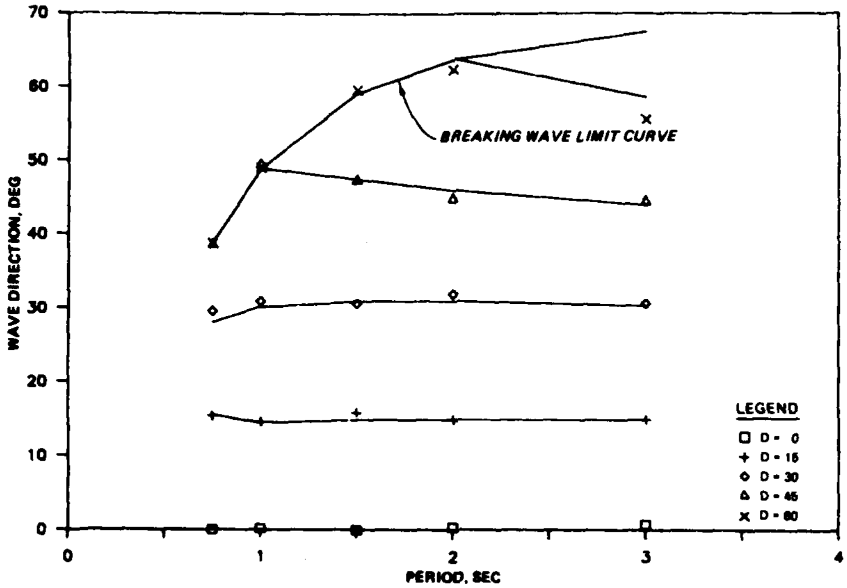


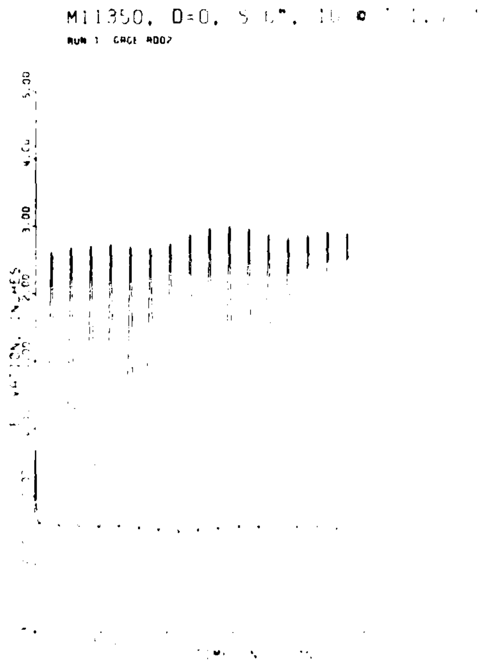
Figure 26. Measured average versus theoretical wave directions for all directions, depth = 1 ft

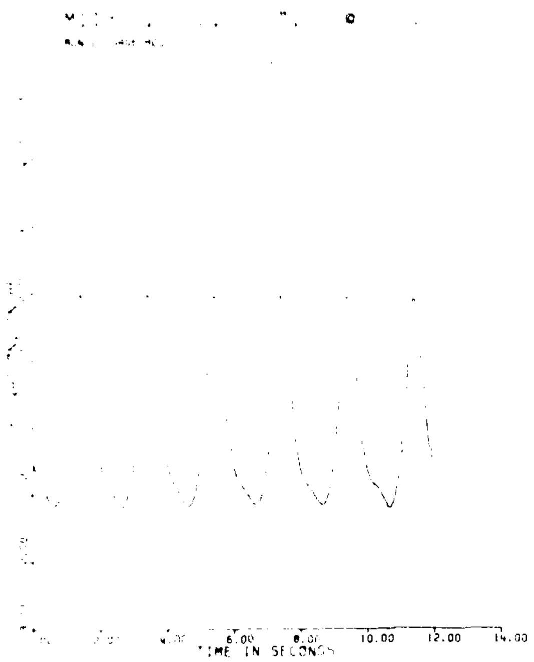
Wave profile analysis

88. Effect of wave period on linear- and nonlinear-generated wave profiles is illustrated in Figure 27. Figures 27a-c show wave profiles for linear waves measured at the center of the first row of the measurement area (i.e. X = 10 ft, Y = 45 ft) for a 6-in. stroke and 0-deg wave direction for the three wave periods 1.5, 2.0, and 3.0 sec, respectively. Figures 27d-f illustrate comparable wave profiles for nonlinear waves. The linear control signal profiles illustrate the binding of higher harmonic waves to form a nonlinear wave. Nonlinear control signal profiles for the 3.00-sec period (Figure 27f) illustrate a possible mismatch in the control signal as an FHW is evident along the front side of the crests.

89. Figure 28 illustrates the effect of wavemaker stroke on linear- and nonlinear-generated wave profiles. Figures 28a-c show measured results for linearly generated control signals for a fixed 3.00-sec period and wave direction of 0 deg for the three wavemaker strokes of 6, 9, and 11 in., respectively. Again, Figures 28d-e show analogous nonlinear wave profiles. The linear control signal profiles are again nonlinear in shape. The nonlinear control signal profiles indicate a strong FHW for both 6- and 9-in. wavemaker strokes.

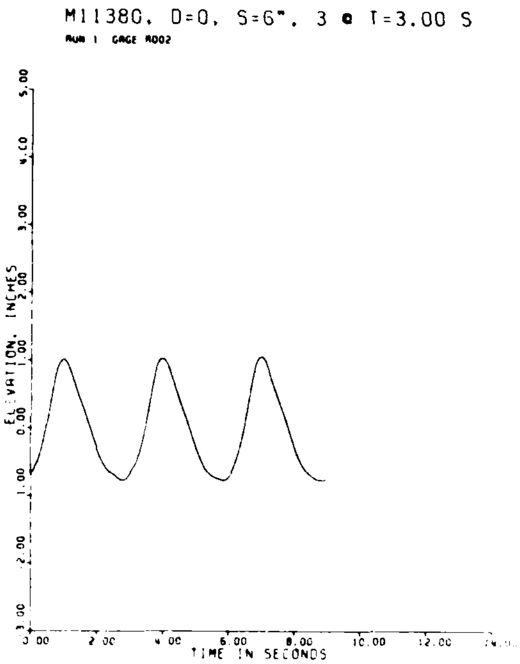
a. Linear waves of 1.50-sec period



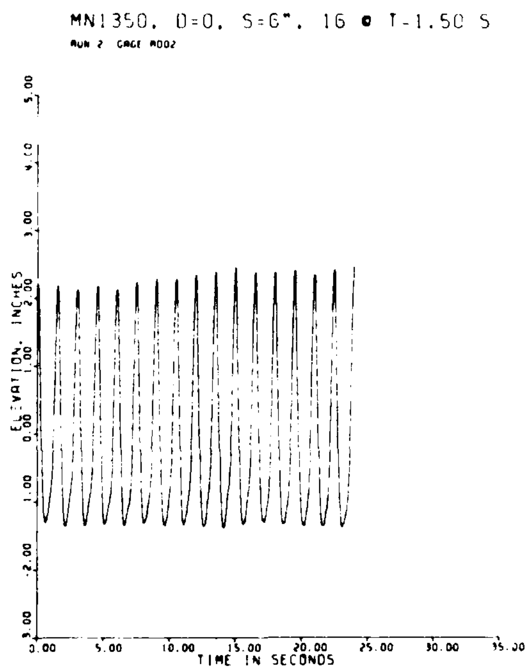


b. Linear waves of 2.00-sec period

Figure 27. Wave profile, effect of wave period
(Sheet 1 of 3)

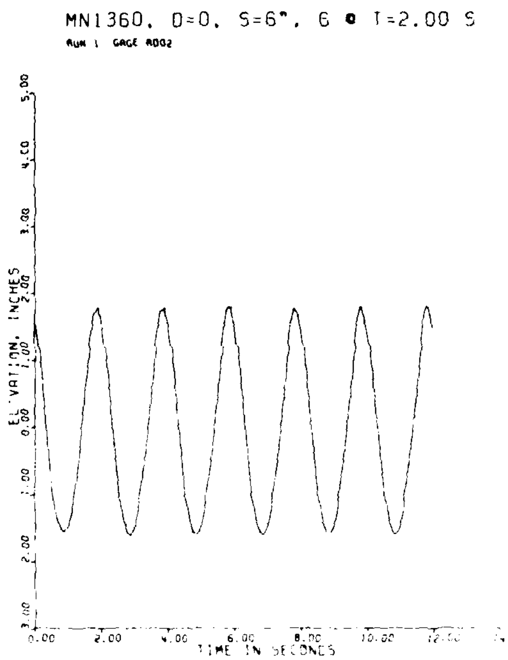


c. **Linear waves of 3.00-sec period**

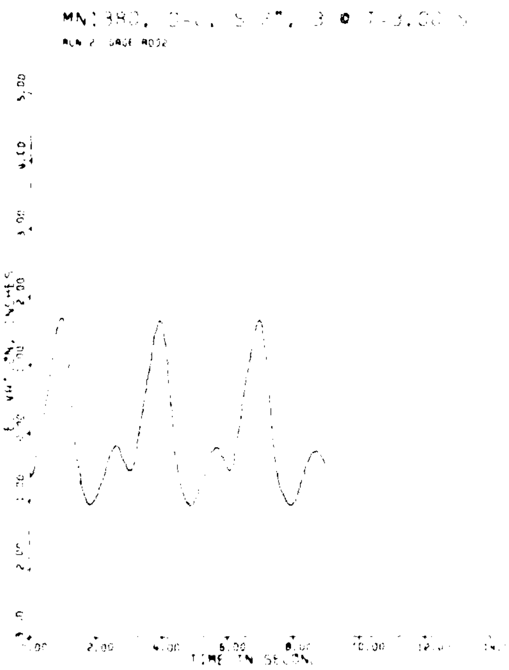


d. **Nonlinear waves of 1.50-sec period**

Figure 27. (Sheet 2 of 3)

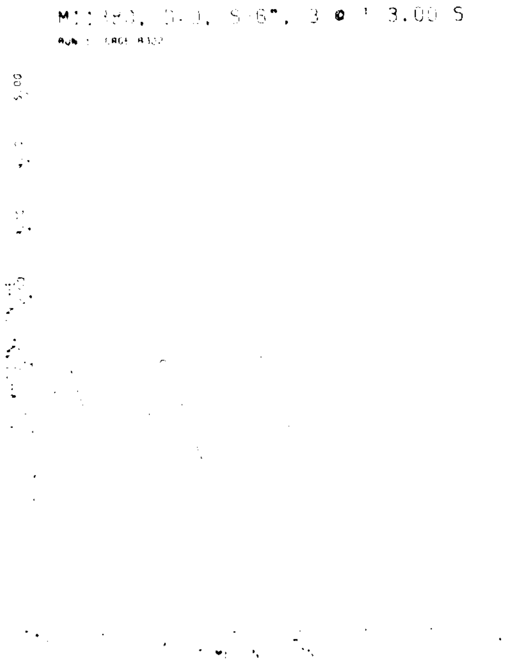


e. Nonlinear waves of 2.00-sec period



f. Nonlinear waves of 3.00-sec period

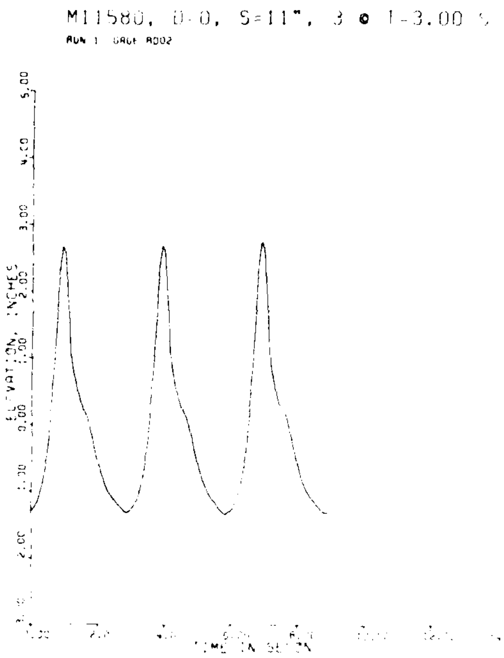
Figure 27. (Sheet 3 of 3)



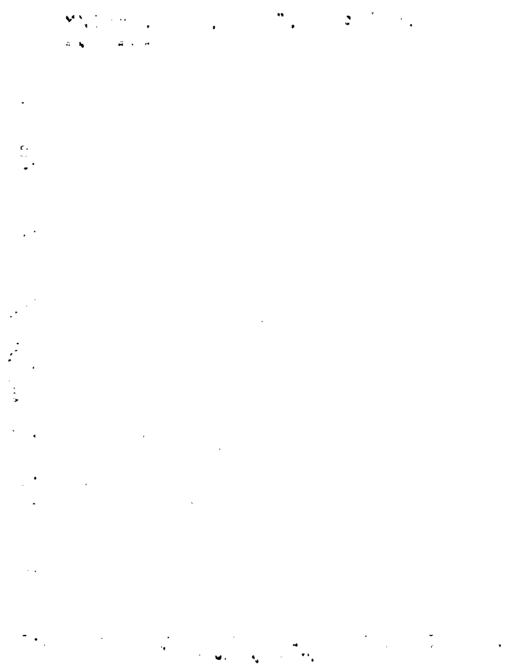
a. Linear waves of 6-in. stroke

b. Linear waves of 9-in. stroke

Figure 28. Wave profile, effect of wavemaker stroke
(Sheet 1 of 3)

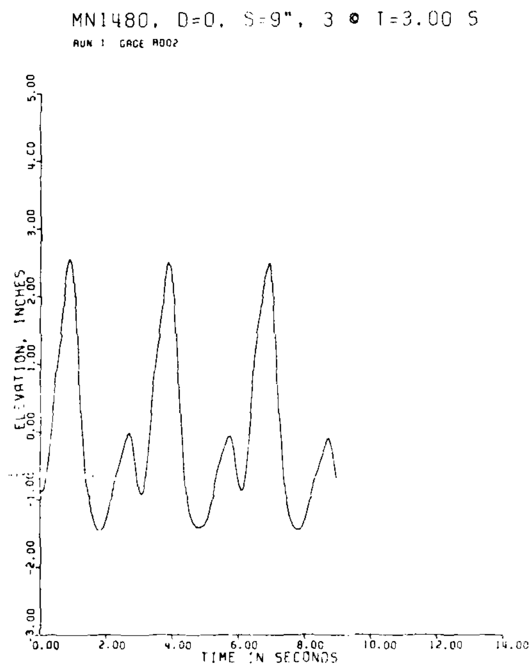


c. Linear waves of 11-in. stroke



d. Nonlinear waves of 6-in. stroke

Figure 28. (Sheet 2 of 3)



e. Nonlinear waves of 9-in. stroke

Figure 28. (Sheet 3 of 3)

90. Finally, Figure 29 shows the effect of wave direction on wave profiles for linear and nonlinear control signals. Figures 29a-b illustrate this directional effect for linear wave cases for a fixed period of 1.50 sec, stroke of 6 in., and wave directions of 0 and 30 deg, respectively. Figures 29c-d show the corresponding effect on nonlinear wave signals. The three-dimensional effect of directionality is evident in these figures. Transformation of the linearly generated wave to a nonlinear shape indicates the need to use nonlinear control signals for these particular combinations of wave parameters.

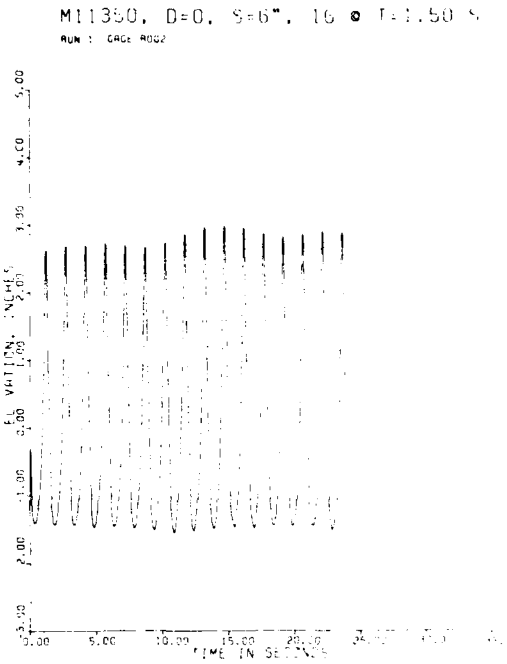
<u>Wave period analysis</u>

91. A comparison of the measured and theoretical nonlinear wave periods for 0- and 30-deg wave directions is given in Table 21. The overall agreement is quite good, with BRF's of 99.7 percent for both the 0- and 30-deg wave directions.

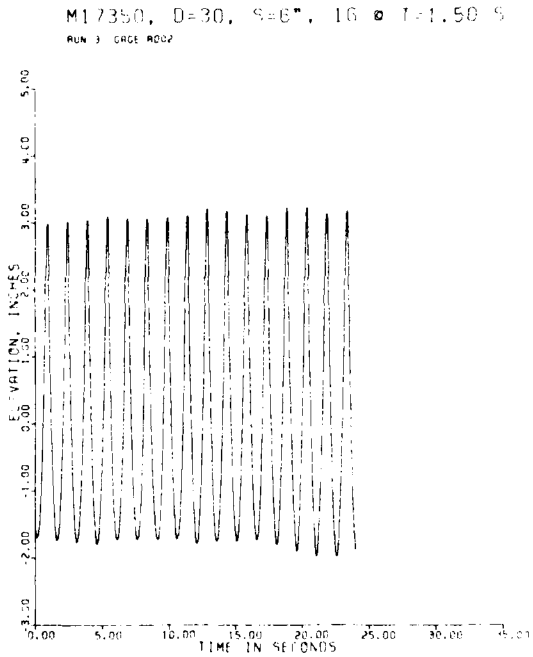
92. Goda (1983) verified the applicability of his nonlinear parameter Π for describing the nonlinearity of water waves from deep to shallow water using regular laboratory waves and strokes third-order and second-order cnoidal wave theory. Nonlinear cnoidal waves can be decomposed into the relative magnitudes of their Fourier components of wave profiles using harmonic analysis. The more nonlinear the wave profile, the larger the percent variance in the higher harmonics relative to the first harmonic. The average percent variance in the first harmonic for nine gages versus Goda's nonlinear parameter Π for linear and nonlinear waves is presented in Table 22 and Figure 30. For both linear and nonlinear waves, this value decreases with increasing Π. There appears to be a crossover at a certain value of Π where the nonlinear control signal better represents the desired waveform (i.e., the variance in the first harmonic is larger for the nonlinear wave relative to the linear wave). Based upon the limited data available, this appears to be approximately a Π of 0.27 to 0.29.

<u>Wave height analysis</u>

93. Table 23 shows measured versus theoretical wave heights for nonlinear waves for wave directions 0 and 30 deg (assuming that a wavemaker stroke of 6, 9, or 11 in. will generate a wave height of comparable value). In all cases, the measured wave heights were much smaller than the assumed values. Thus, the BRF factors reported here are representative of more than just the DSWG basin efficiency as defined for linear waves, but also include

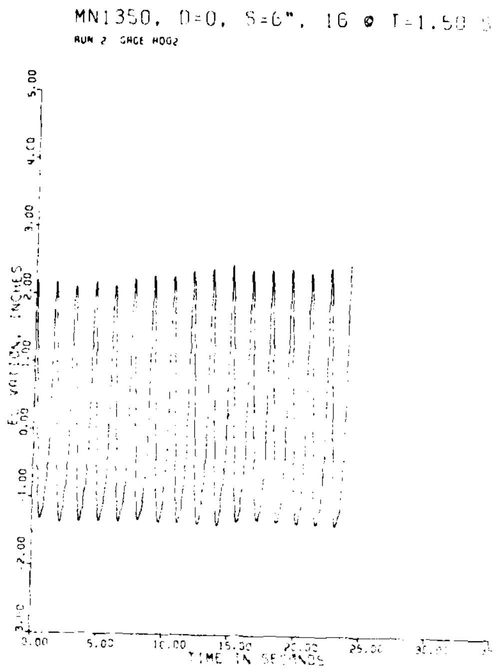


a. Linear waves of 0-deg wave direction

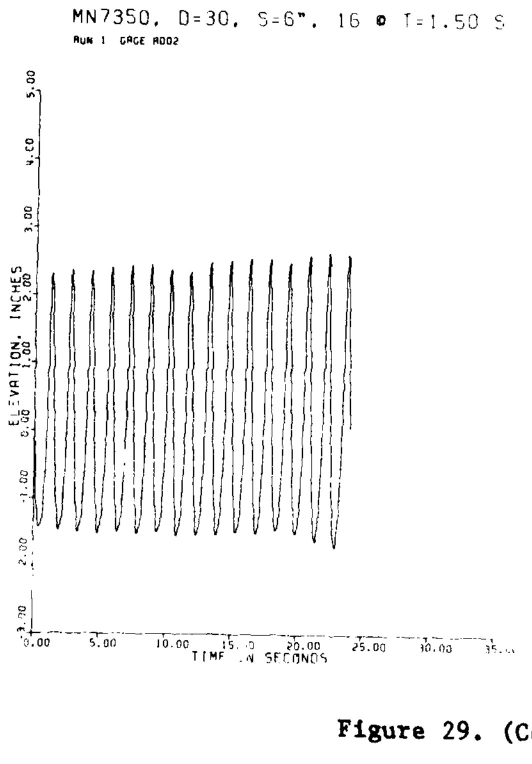


b. Linear waves of 30-deg wave direction

Figure 29. Wave profile, effect of wave direction (Continued)



c. Nonlinear waves of 0-deg wave direction



d. Nonlinear waves of 30-deg wave direction

Figure 29. (Concluded)

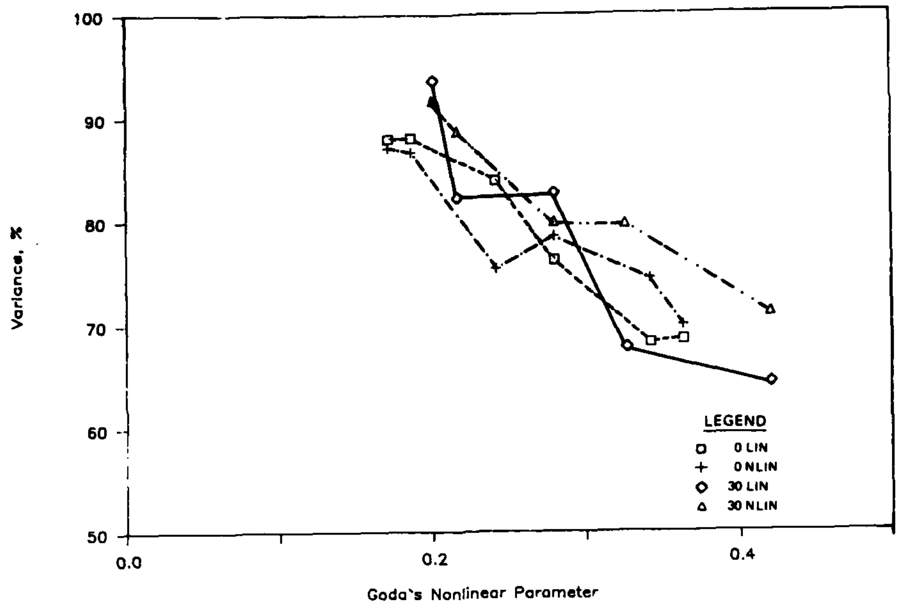


Figure 30. Linear versus nonlinear harmonic analysis results

the effect of the wave generator transfer function. The measured wave heights decrease with increasing period for a fixed value of DSWG stroke, just as for linear waves. It also decreases with increasing stroke for a fixed wave period. Breaking occurred in some of the cases reported. This resulted in a smaller wave height than would be present had breaking and subsequent loss of energy not occurred. The purpose of reporting these values is to give some indication of the wave height magnitude and where wave breaking becomes a serious consequence for nonlinear waves.

<u>Wave direction analysis</u>

94. Table 24 lists measured versus theoretical wave directions for desired wave directions of 0 and 30 deg. Agreement is excellent for the 0-deg cases. Measured values were considerably higher for a desired wave angle of 30 deg for nonlinear waves relative to the linear waves (see Table 18). The BRF for a wave direction of 0 deg is 99.9 percent and 82.9 percent for 30 deg.

PART VI: SUMMARY AND RECOMMENDATIONS

95. The directional spectral wave generator (DSWG) is a unique resource for the study of natural sea states in a laboratory environment. Its unique features include size, modular design, portability, method of paddle connection and displacement, and electric motor power. More economical and efficient design of coastal structures will result because of the use of the DSWG facility in site-specific and research studies.

96. A series of 111 linear and nonlinear control signals were generated to quantify performance characteristics of the DSWG basin. Measurements were made at nine locations within the basin by resistance-wire wave gages. Comparisons of measured versus predicted wave profiles, periods, heights, and directions indicate the range of applicability of linear control signal theory.

97. The linear control signals consisted of combinations of five wave periods (i.e. 0.75, 1.00, 1.50, 2.00, and 3.00 sec), five wavemaker strokes (i.e. 1, 3, 6, 9, and 11 in.), and five wave directions (i.e. 0, 15, 30, 45, and 60 deg) representative of model test conditions for monochromatic waves. Of the 125 possible combinations (i.e. five periods by five strokes by five directions), only 80 were actually tested because certain combinations of period, stroke, and direction are impossible to generate without wave breaking occurring.

98. A basin response factor (BRF) was calculated to indicate the ability of the basin to accurately reproduce theoretically predicted wave parameters. It is the ratio of the measured average value for all nine gages to the theoretical value. The measured wave periods show excellent agreement with the predicted values. The average BRF for all wave strokes and directions is 99.6 percent.

99. A least-squares harmonic analysis was performed to quantify the variance (total energy) contained in the fundamental harmonic component. The larger this value, the more linear the actual waveform. Goda's nonlinear parameter Π also was calculated. Wave conditions with Π values less than 0.2 have approximately 85 percent or more of their total energy (variance) in the first harmonic. This indicates a reasonably linear wave profile.

100. The height-to-stroke ratios predicted by linear wave theory generally overpredict the measured wave heights for different wave period, stroke,

and direction combinations. The only exception was for 3-sec period, 11-in. stroke waves of direction less than 30 deg. The average BRF for all period and stroke combinations at 0 deg is 87.7 percent, decreasing to 79.2 percent for all directions. The general trend is for the BRF to increase with increasing stroke for a fixed wave direction and to decrease with wave direction for all stroke combinations. A major cause for lower than predicted wave heights is the fact that the DSWG is not sealed at the ends and along the bottom. This results in a loss of energy from the wave field as waves are generated and a corresponding loss in generated wave height. Measured wave heights for different wave directions did not always agree well with predicted values using first-order theory. Additional research on second-order effects of directionality on height-to-stroke ratios would be beneficial.

101. Constancy of mean wave height was calculated for several cases with wave periods of 1.00 and 1.50 sec. Although some measured wave heights appear to vary more than expected, the variation in mean wave height $\Delta\bar{H}$ was always less than the 15 to 25 percent tolerance limits suggested by Sand (1979). The value of $\Delta\bar{H}$ always followed the same pattern observed by Sand of increasing with increasing wave direction. The most probable sources of this variation are the interaction of free and bound higher harmonics, wave reflections, end diffraction, Benjamin-Feir type of effect due to low frequency standing cross waves, asymmetry of the basin, variable bottom gap, and wave gage calibration tolerances. Additional research is needed in these areas, especially prediction and control of higher harmonics, improved wave absorption for the beaches and side walls, and effect of calibration tolerances on repeatability of wave gages.

102. The design of connections between paddles of the DSWG allows generation of waves of a directional range approaching ±90 deg for all wave periods larger than 1.00 sec. For periods less than this, the maximum wave direction is reduced due to the requirement for at least two paddles per wavelength along the wave generator. A more reasonable upper limit for 0.75-sec waves using slightly more than two paddles is about 70 deg. The agreement between predicted and measured wave directions was excellent for all linear wave cases. The average BRF for a wave direction of 0 deg is 99.9 percent, decreasing to 98.8 percent for all cases. Thus, the snake principle works very well in predicting wave directions in the DSWG basin. Since wave directions were calculated manually for this study, it is recommended that a

cross-correlation technique be implemented for future projects. An option should be included to calculate the phase lag between pairs of wave gages and to use a specific gage pair or the average of all possible pairs.

103. Certain wave period and height combinations produce waves which tend to deviate from the linear wave profile. These waves become more nonlinear with higher, sharper crests and broader, flatter troughs due to a second-order effect of a bounded (or locked) higher harmonic wave component (BHW). If linear control signal theory is used for these waves, boundary conditions at the wavemaker cannot be satisfied for the second-order BHW (i.e., a mismatch in wavemaker motion with the required water particle velocities) resulting in the creation of spurious or free higher harmonic component waves (FHW). These FHW's are a primary cause of the variations in wave height, discussed earlier, due to alternate cancellation and reinforcement with the BHW. Thus, to ascertain the importance of nonlinear, second-order control theory, a series of 16 cnoidal waves was created and tested in the DSWG basin.

104. Comparisons of several linear wave profiles revealed the binding of a BHW to form a nonlinear waveform. The nonlinear profiles for 3.00 sec illustrate a possible mismatch of the control signal as an FHW is evident along the front side of the crests.

105. The wave periods for nonlinear waves, as in the linear case, showed good agreement with predicted values. The average BRF's for both the 0- and 30-deg cases were 99.7 percent.

106. A comparison of harmonic analysis results between several linear and nonlinear cases indicates that nonlinear control signals might better represent desired waveforms around a Π value of 0.27 to 0.29. Further research into this relationship with Goda's nonlinear parameter is recommended.

107. For nonlinear waves, the height-to-stroke ratios were not considered in the initial determination of required stroke (as was done for linear wave cases). Thus, measured wave heights were quite a bit smaller than assumed values, and the BRF's comprise height-to-stroke ratios in addition to basin efficiency. Therefore, it is not valid to compare them with comparable linear BRF's. Trends are the same, however, as for linear waves.

108. The measured versus theoretical wave directions for directions of 0 deg agreed very well with a BRF of 99.9 percent. For the 30-deg wave direction, however, the nonlinear waves do not show as good agreement as the linear

waves. The BRF was 82.9 percent with the measured values 3 to 5 deg above the corresponding linear values.

109. Tests with nonlinear control signals were not intended to be exhaustive. Additional tests should be run to better quantify applicable ranges of use relative to linear control theory. Also, further study of the theoretical development and verification of the height-to-stroke ratio should be pursued.

110. The DSWG basin bathymetry is relatively constant over the 90- by 70-ft area in front of the DSWG. The maximum total variation is 1.08 in. The highest point is 0.51 in. (4.3 percent in 1 ft of water) and the lowest point is -0.57 in. (4.8 percent in 1 ft of water), and they are located in opposite corners of the basin. The standard deviation for the basin is 0.18 in. For the 20- by 20-ft measurement area, the maximum total variation is 0.35 in. The high point is 0.08 in. (0.7 percent in 1 ft of water) and the low point is -0.27 in. (2.3 percent in 1 ft of water).

111. As a consequence of the finite width of wavemaker paddles, small undesired disturbances known as spurious waves are generated in addition to the main monochromatic wave. Since the DSWG is driven at the joints between paddles rather than at individual paddles, the amplitude of any spurious waves generated is greatly attenuated. Spurious wave generation was not a serious problem in this study due to the wave generator design and period range tested.

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Table 1

ADACS Computer Specifications

Specification	Description
Computer	DEC VAX 11/750
Location	Wave Processes Branch, WES Bldg. 6006
Operating system	VAX/VMS Version 4.2
Operating mode	Interactive, real time, prioritized multitasking
Language	Fortran 77
Memory	4 MB
Disk storage	577 MB fixed 10 MB removable
A/D channels	128 multiplexed, single-ended
D/A channels	61 Preston, IEEE 488 4 DEC
Tape drives	2 @ 125 IPS, 800/1600 BPI
Plotter	Versatec V-80
Terminals	VT 100 compatible Tektronix 4014, 4114-A
Printer	600 LPM, 138 columns

Table 2

Maximum Wave Direction Versus Wave Period

Period sec	Wavelength ft	Exact Values Number Paddles	Offset deg	Direction deg	Integer Values Number Paddles	Offset deg	Direction deg
0.75	2.82	1.88*	191.5	90	3	120	38.8
1.00	4.52	3.01	119.6	90	4	90	48.9
1.50	7.73	5.15	69.9	90	6	60	59.2
2.00	10.77	7.18	50.1	90	8	45	63.8
3.00	16.63	11.09	32.5	90	12	30	67.5

* Impossible to generate, need a minimum of two paddles.

Table 3

Number of Spurious Waves Based on Main Wave Parameters

Period sec	Wavelength ft	Direction deg	Number of Waves
0.25	0.32	0 - 5	7+
0.50	1.28	0 - 8	2
		8 - 25	1
0.75	2.82	0 - 60	0
		60 - 68	1
1.00	4.52	0 - 90	0

Note: Paddle width B = 1.5 ft; water depth h = 1.0 ft.

Table 4

Wave Properties Examined

Function	Wave Property
Waveform	Wavelength Celerity Group speed Dimensionless depth
Transfer	Height-to-stroke ratio Two-dimensional wave height Three-dimensional wave height Maximum prebreaking wave height
Spurious waves	Number of waves Minimum wave period
Wave direction	Paddle offsets Predicted wave direction
Waveform nonlinearity	Steepness ratio Goda's nonlinearity parameter
Measurement times	Beginning delay time Ending delay time

AD-A182 142 DIRECTIONAL SPECTRAL WAVE GENERATOR BASIN RESPONSE TO MONOCHROMATIC WAVES(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS M J BRIGGS ET AL. APR 87 2/2

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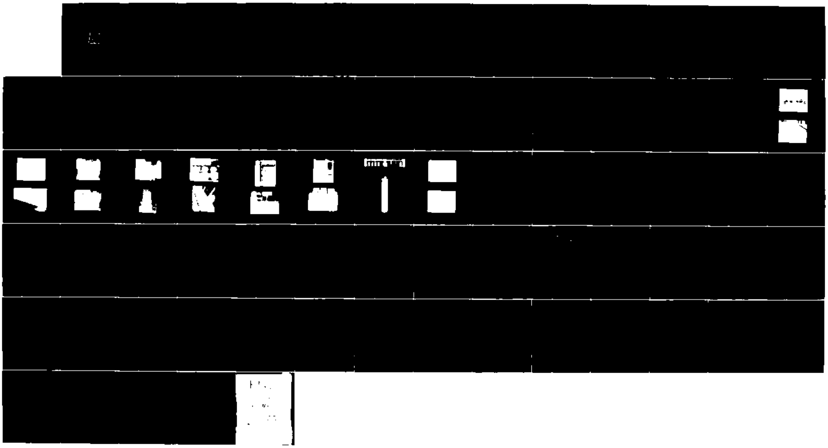


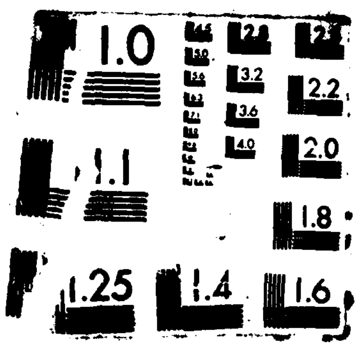

1.0
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Table 5

Description of Subroutines in Program MONOSUMMARY

Name	Description
INPUT	Queries user for input parameters
CASE	Case or run number for individual test cases
HUNT	Hunt's method for wavelength, see CETN-I-17*
SPEED	Wave celerity or speed
KHCALC	Nondimensional water depth ratio
GROUP	Group speed
ANGLE2	Offset angle for integer number of paddles to produce desired wave direction angle
SPURIOUS	Minimum wave period below which spurious waves will be generated
HSRATIO	Two-dimensional wave-height-to-stroke transfer function
HEIGHT	Two-dimensional wave height, same as three-dimensional for zero wave direction
HTHETA	Three-dimensional wave height based on effects of wave direction angle
HBREAK	Maximum breaking wave height for laboratory waves
STEEP	Wave steepness ratio, measure of nonlinearity of waveform
NLPARAM	Goda's nonlinear parameter
DELAY	Delay time prior to data collection, time for specified number of waves to reach back gage row
REFLECT	Trip time for specified wave to travel from wave generation to back wall and return to back gage row
HD120	Maximum breaking wave height based on 120-deg maximum crest angle

* US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center (1985).

Table 6

Input Variables for Program MONOSUMMARY

Name	Description	Comment
NTHETA	Number of wave direction angles	Maximum number = 25
THETA	Array of wave angles, deg	Enter NTHETA values
NSTROKE	Number of generator strokes	Maximum number = 25
STROKE	Array of generator strokes, in.	Enter NSTROKE values
NPERIOD	Number of wave periods	Maximum number = 25
PERIOD	Array of wave periods, sec	Enter NPERIOD values
H	Water depth, ft	
DISTNC1	Distance to back gage row, ft	Used in delay time calculation
NWAVE	Number of waves to pass before testing	Used in delay time calculation
DISTNC2	Trip distance to back wall and return to back gage row	Maximum time before reflected energy could return
TITLE2	Descriptive title for project	.LE. 40 characters
TITLE3	Descriptive title for line 3	.LE. 40 characters
SERIES	Test series description	1 character (i.e. M = Monochromatic)
MONTH	Month of test	1 character (i.e. 2 = Feb)
LOCATION	Test location	1 character (i.e. 0 = Initial setup)

Table 7

Output Variables for Program MONOSUMMARY

Name	Description	Comment
HDMAX	Maximum breaking height	Assumes H/D = 0.78
NAME	Case or run number identification	6 characters
T	Period, sec	
L	Shallow-water wavelength, ft	Assumes linear theory
C	Wave speed or celerity, fps	
CG	Group speed, fps	
OFFSET	Offset phase angle corresponding to desired wave angle, deg	See Part III, para 32
DIR	Wave angle generated, deg	See Part III, para 32
TMIN	Minimum wave period to avoid generation of spurious waves, sec	See Part III, para 35
KH	Nondimensional water depth	
HSR	Height-to-stroke ratio for two-dimensional transfer function	See Part III, para 21
HO	Wave height based on height-to-stroke ratio, in.	
HT	Wave height based on three-dimensional transfer function	See Part III, para 23
HMAX	Maximum prebreaking wave height	See Part III, para 24
HLR	Wave steepness ratio	Measure of nonlinearity, see Part III, para 39
PNL	Goda's dimensionless nonlinear parameter	Measure of nonlinearity, see Part III, para 39
TIME1	Time prior to data collection	See Part III, para 49
TIME2	Time for specified wave to travel to back wall and return	See Part III, para 49

Table 8

Summary of Input Parameters for Process IDCAL

Header 2 Variables

Line 1 Period, sec	Line 2 Scans/Period	Line 3 Records/Period	Line 4 Number of Periods	Line 16 Updates/Period
0.75	38	38	64	150
1.00	50	50	48	200
1.50	75	75	16	300
2.00	100	100	6	400
3.00	150	150	3	600

Table 9

Relative Times for Data Collection

Period sec	Number of Test Periods	Test Duration sec	Generator Start Delay sec	Measurement Delay sec	Run Time sec
0.75	64	48	10	30	60
1.00	48	48	10	24	60
1.50	16	24	10	21	40
2.00	6	12	10	16	25
3.00	3	9	10	13	25

Table 10

Absolute Times for Data Collection

Period sec	Start Test sec	Start DSWG sec	Begin Data sec	End Data sec	End DSWG sec
0.75	0	10	40	88	100
1.00	0	10	34	82	94
1.50	0	10	31	55	71
2.00	0	10	26	38	51
3.00	0	10	23	32	48

Table 11

Summary of Test Case Parameters, Monochromatic Performance Tests in DSWG Basin

Test ID	Period sec	Test Duration: Number of waves	Test Duration: sec	C_g fps	Travel Time: Time1 sec	Travel Time: Time2 sec	Data Collection: Number	Data Collection: Begin sec	Data Collection: End sec
MPTST9	0.75	120	90	2.07	14.5	74.4	64	30	78
MPTST1	1.00	90	90	3.04	9.9	50.6	48	24	72
MPTST6	1.50	60	90	4.29	7.0	35.9	16	21	45
MPTST2	2.00	60	120	4.86	6.2	31.7	6	16	28
MPTST3	3.00	20	60	5.29	5.7	29.1	3	13	22

Table 12

Wave Period Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Periods
Direction = 0 Deg, Depth = 1 Ft Overall BRF, %: 99.65
February/March 86

Period (Sec)	S=1" Meas (Sec)	S=3" Meas (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
0.75	0.740	0.740				0.740	98.67
1.00	1.000	1.000	1.000			1.000	100.00
1.50	1.501	1.500	1.502	1.502		1.501	99.92
2.00	1.999	1.999	1.999	1.997	1.998	1.998	99.92
3.00	2.974	2.994	3.002	2.998	2.997	2.993	99.77

Waves of 15 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Periods
Direction = 15 Deg, Depth = 1 Ft Overall BRF, %: 99.61
February/March 86

Period (Sec)	S=1" Meas (Sec)	S=3" Meas (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
0.75	0.740	0.740				0.740	98.67
1.00	1.000	1.000				1.000	100.00
1.50	1.499	1.500	1.500			1.500	99.98
2.00	1.999	1.999	2.031	1.997		2.007	99.68
3.00	2.996	2.982	3.000	2.987	2.994	2.992	99.73

(Continued)

Table 12. (Continued)

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Periods
Direction = 30 Deg, Depth = 1 Ft   Overall BRF, %:   99.63
February/March 86

Period (Sec)	S=1" Meas (Sec)	S=3" Meas (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
0.75	0.740					0.740	98.67
1.00	1.000	1.000				1.000	100.00
1.50	1.501	1.500	1.499			1.500	100.00
2.00	2.002	2.000	2.028	1.998		2.007	99.65
3.00	2.992	3.003	3.003	2.990	2.988	2.995	99.84

Waves of 45 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Periods
Direction = 45 Deg, Depth = 1 Ft   Overall BRF, %:   99.51
February/March 86

Period (Sec)	S=1" Meas (Sec)	S=3" Meas (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
0.75	0.740					0.740	98.67
1.00	1.000	0.998				0.999	99.90
1.50	1.500	1.499	1.495			1.498	99.87
2.00	1.999	1.996	1.992	2.002		1.997	99.86
3.00	2.993	2.979	2.977	2.978	2.962	2.978	99.26

(Continued)

Table 12. (Concluded)

<u>Waves of 60 deg</u>

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Periods
Direction = 60 Deg, Depth = 1 Ft   Overall BRF, %:   99.33
February/March 86

Period (Sec)	S=1" Meas (Sec)	S=3" Meas (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
0.75	0.740					0.740	98.67
1.00	1.000	0.997				0.999	99.85
1.50	1.501	1.497	1.497			1.498	99.89
2.00	1.993	1.989	1.992	1.985		1.990	99.49
3.00	2.999	3.003	2.990	2.935	2.883	2.962	98.73

Table 13

Measured Average Wave Periods for All Wave Directions

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured Average vs. Theoretical Wave Periods
Depth = 1 Ft   Overall BRF, %: 99.61
February/March 86

Period (Sec)	Dir=0 Ave (Sec)	Dir=15 Ave (Sec)	Dir=30 Ave (Sec)	Dir=45 Ave (Sec)	Dir=60 Ave (Sec)	Overall Ave (Sec)	BRF (%)
0.75	0.740	0.740	0.740	0.740	0.740	0.740	98.67
1.00	1.000	1.000	1.000	0.999	0.999	1.000	99.96
1.50	1.501	1.500	1.500	1.498	1.498	1.499	99.96
2.00	1.998	2.007	2.007	1.997	1.990	2.000	99.99
3.00	2.993	2.992	2.995	2.978	2.962	2.984	99.47

Table 14

Harmonic Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Harmonic Analysis of Linear Waves
Percent Variance in First Harmonic
Direction = 0 Deg Depth = 1 Ft
February/April 86

	S=1"		S=3"		S=6"		S=9"		S=11"	
Period (Sec)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)
0.75	0.056	99.6								
1.00	0.035	99.7	0.105	97.2						
1.50	0.029	99.8	0.086	98.5	0.172	88.0				
2.00	0.031	99.7	0.093	97.4	0.187	89.1	0.280	76.2	0.342	68.2
3.00	0.040	99.7	0.121	96.7	0.242	83.9	0.363	68.5	0.443	57.9

Waves of 15 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Harmonic Analysis of Linear Waves
Percent Variance in First Harmonic
Direction = 15 Deg Depth = 1 Ft
February/April 86

	S=1"		S=3"		S=6"		S=9"		S=11"	
Period (Sec)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)
0.75	0.058	99.6								
1.00	0.036	99.8	0.109	96.4						
1.50	0.030	99.9	0.089	98.7	0.178	87.8				
2.00	0.032	99.6	0.097	97.2	0.193	89.0	0.290	75.8		
3.00	0.042	99.4	0.125	96.5	0.250	84.4	0.375	68.4	0.459	56.4

(Continued)

(Sheet 1 of 3)

Table 14. (Continued)

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Harmonic Analysis of Linear Waves
Percent Variance in First Harmonic
Direction = 30 Deg   Depth = 1 Ft
February/April 86

	S=1"		S=3"		S=6"		S=9"		S=11"	
Period (Sec)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)
0.75	0.064	99.6								
1.00	0.041	99.8	0.122	97.5						
1.50	0.034	99.9	0.101	98.4	0.201	93.6				
2.00	0.036	96.2	0.109	96.2	0.217	82.2	0.326	67.7		
3.00	0.047	99.1	0.140	96.3	0.280	82.6	0.420	64.2	0.513	52.9

Waves of 45 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Harmonic Analysis of Linear Waves
Percent Variance in First Harmonic
Direction = 45 Deg   Depth = 1 Ft
February/April 86

	S=1"		S=3"		S=6"		S=9"		S=11"	
Period (Sec)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)
0.75	0.072	99.4								
1.00	0.053	99.8	0.128	95.8						
1.50	0.042	99.6	0.127	96.4						
2.00	0.045	99.4	0.134	94.3	0.268	77.0				
3.00	0.056	99.1	0.168	92.8	0.335	70.4	0.503	36.8	0.614	36.4

(Continued)

(Sheet 2 of 3)

Table 14. (Concluded)

Waves of 60 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Harmonic Analysis of Linear Waves
Percent Variance in First Harmonic
Direction = 60 Deg   Depth = 1 Ft
February/April 86

	S=1"		S=3"		S=6"		S=9"	
Period (Sec)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)	Goda NLP	Var (%)
0.75	0.072	95.3						
1.00	0.053	99.3						
1.50	0.056	99.5	0.169	93.9				
2.00	0.070	97.5	0.211	87.3	0.362	53.7		
3.00	0.077	98.8	0.231	91.3	0.463	64.6	0.694	40.9

Table 15

Wave Height Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Heights
Direction = 0 Deg, Depth = 1 Ft
February 86

Overall BRF, %: 87.65

	Max	Stroke = 1"		Stroke = 3"		Stroke = 6"		Stroke = 9"		Stroke = 11"	
Period (Sec)	Height (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)
0.75	3.30	1.55	1.77	3.08	3.30						
1.00	4.79	1.07	1.31	3.27	3.94						
1.50	6.23	0.60	0.81	1.77	2.42	3.95	4.83				
2.00	6.79	0.41	0.58	1.33	1.75	2.80	3.49	5.06	5.24	6.38	6.40
3.00	7.20	0.23	0.38	0.81	1.13	1.91	2.27	3.22	3.40	4.26	4.16
BRF, %:		79.59		81.82		81.78		95.83		99.24	

Notes:
1. Slight Breaking Occurred
2. BD = Bad Data

Waves of 15 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Heights
Direction = 15 Deg, Depth = 1 Ft
February/March 86

Overall BRF, %: 84.68

	Max	Stroke = 1"		Stroke = 3"		Stroke = 6"		Stroke = 9"		Stroke = 11"	
Period (Sec)	Height (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)	Meas (In)	Theory (In)
0.75	3.30	1.48	1.84								
1.00	4.79	1.04	1.36	3.34	4.07						
1.50	6.23	0.56	0.83	1.83	2.50	4.26	5.00				
2.00	6.79	0.38	0.60	1.30	1.81	2.87	3.61	5.00	5.42		
3.00	7.20	0.25	0.39	0.85	1.17	1.96	2.35	3.37	3.52	4.46	4.30
BRF, %:		73.90		76.65		82.94		93.62		96.28	

Notes:
1. Slight Breaking Occurred
2. BD = Bad Data

(Continued)

Table 15. (Continued)

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Heights
Direction = 30 Deg, Depth = 1 Ft — Overall BRF, %: 81.60
February/March 86

Period (Sec)	Max Height (In)	Stroke = 1" Meas (In)	Stroke = 1" Theory (In)	Stroke = 3" Meas (In)	Stroke = 3" Theory (In)	Stroke = 6" Meas (In)	Stroke = 6" Theory (In)	Stroke = 9" Meas (In)	Stroke = 9" Theory (In)	Stroke = 11" Meas (In)	Stroke = 11" Theory (In)
0.75	3.30	1.36	2.01								
1.00	4.79	1.11	1.52	3.30	4.55						
1.50	6.23	0.59	0.94	1.98	2.82	4.49	5.64				
2.00	6.79	0.40	0.68	1.40	2.03	3.42	4.07	5.62	6.10		
3.00	7.20	0.20	0.44	0.82	1.31	2.00	2.62	3.65	3.94	4.80	4.81
BRF, %:		65.47		70.03		80.37		92.33		99.79	

Notes:
1. Slight Breaking Occurred
2. BD = Bad Data

Waves of 45 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Heights
Direction = 45 Deg, Depth = 1 Ft — Overall BRF, %: 69.21
February/March 86

Period (Sec)	Max Height (In)	Stroke = 1" Meas (In)	Stroke = 1" Theory (In)	Stroke = 3" Meas (In)	Stroke = 3" Theory (In)	Stroke = 6" Meas (In)	Stroke = 6" Theory (In)	Stroke = 9" Meas (In)	Stroke = 9" Theory (In)	Stroke = 11" Meas (In)	Stroke = 11" Theory (In)
0.75	3.30	1.32	2.27								
1.00	4.79	1.15	2.00	4.04	4.79						
1.50	6.23	0.71	1.19	2.50	3.57	5.03	6.23				
2.00	6.79	0.40	0.84	1.55	2.51	4.16	5.02	4.54	6.79		
3.00	7.20	0.24	0.52	0.93	1.57	2.53	3.14	BD	4.71	BD	5.76
BRF, %:		56.01		72.51		81.45		66.86			

Notes:
1. Slight Breaking Occurred
2. BD = Bad Data

(Continued)

Table 15. (Concluded)

Waves of 60 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Heights
Direction = 60 Deg, Depth = 1 Ft — Overall BRF, %: 72.71
February/March 86

Period (Sec)	Max Height (In)	Stroke = 1" Meas (In)	Stroke = 1" Theory (In)	Stroke = 3" Meas (In)	Stroke = 3" Theory (In)	Stroke = 6" Meas (In)	Stroke = 6" Theory (In)	Stroke = 9" Meas (In)	Stroke = 9" Theory (In)	Stroke = 11" Meas (In)	Stroke = 11" Theory (In)
0.75	3.30	1.92	2.27								
1.00	4.79	1.16	2.00	4.50	4.79						
1.50	6.23	0.92	1.58	3.17	4.73						
2.00	6.79	0.54	1.32	2.22	3.95	4.50	6.79				
3.00	7.20	0.28	0.72	1.37	2.17	3.16	4.34	5.37	6.51	5.70	7.20
BRF, %:		61.09		71.99		68.82		82.49		79.17	

Note:
1. Slight Breaking Occurred
2. BD = Bad Data

(Sheet 3 of 3)

Table 16

Breaking Wave Tests

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Breaking Wave Tests
Depth = 1 Ft
February 86

	Theory		Below Breaking		Near Breaking		Above Breaking	
Period (Sec)	Stroke (In)	Height (In)	Stroke (In)	Height (In)	Stroke (In)	Height (In)	Stroke (In)	Height (In)
0.75	1.86	3.30	2.05	2.66	2.40	2.95	2.70	3.01
1.00	3.65	4.79	4.03	4.45	4.39	4.75	4.60	4.95
1.50	7.69	6.23	7.69	5.35	8.46	6.14	8.70	6.10
2.00	11.70	6.79	10.20	5.76	11.20	6.30	11.71	6.37
3.00	18.90	7.20	11.90	4.67				

Table 17

Constancy of Measured Wave Heights

Period (Sec)	Dir (Deg)	Theory Height (In)	Measured Wave Height, In: X = 10 Ft, 35	45	55	X = 20 Ft, 35	45	55	X = 30 Ft, 35	45	55	$\bar{H}$	$\Delta\bar{H}$ (%)
							Small Wave Gages						
1.00	0	3.94	2.932	2.953	3.075	3.596	3.558	3.442	3.245	3.215	3.029	3.316	7.8
	15	4.07	2.732	2.691	3.536	3.305	3.336	3.491	3.022	3.299	3.724	3.340	8.0
	30	4.55	2.926	3.179	3.094	3.320	3.572	2.984	3.983	3.001	3.363	3.269	7.9
	45	BR	4.224	4.348	3.965	4.105	3.748	3.360	3.410	2.000	2.548	3.626	14.4
1.50	0	2.42	2.028	1.776	1.778	1.635	1.571	1.795	1.971	1.941	1.939	1.826	7.1
	15	2.50	1.826	2.001	1.934	1.712	2.095	1.827	2.182	1.599	1.755	1.881	8.1
	30	2.82	2.057	1.885	2.090	2.003	2.036	2.004	1.719	1.990	2.218	2.019	5.0
	45	3.57	2.266	2.674	2.917	3.246	2.849	2.064	2.259	1.940	1.520	2.415	10.6
							Jordan Wave Gages						
1.00	0	3.94	3.158	3.000	2.545	3.350	3.639	3.281	3.364	2.755	3.956	3.236	9.7
	15	4.07	3.013	3.747	3.383	3.185	3.357	3.288	2.840	3.234	3.934	3.331	7.3
	30	4.55	2.791	3.477	2.766	3.800	3.770	2.943	4.063	2.770	3.339	3.302	13.1
	45	BR	4.315	4.477	4.264	3.726	3.808	3.137	3.654	2.616	2.216	3.579	17.2
1.50	0	2.42	1.820	1.681	1.720	1.775	1.507	1.706	1.723	1.715	1.759	1.712	3.1
	15	2.50	1.627	1.763	1.775	1.787	2.172	1.822	1.805	1.514	1.620	1.765	6.7
	30	2.82	1.983	1.812	1.945	2.025	1.966	2.125	1.493	1.936	2.046	1.926	6.3
	45	3.57	2.051	2.513	2.745	3.064	2.712	1.981	1.932	1.632	1.230	2.207	22.2

Notes:

1. BR = Wave height should exceed maximum possible pre-breaking wave height.

Table 18

Wave Direction Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Directions
Direction = 0 Deg, Depth = 1 Ft   Overall BRF, %: 99.9
February/March 86

Period (Sec)	Theory Direction (Deg)	S=1" Meas (Deg)	S=3" Meas (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	S=11" Meas (Deg)	Meas Ave (Deg)	BRF (%)
0.75	0.0	0.0	0.0				0.0	100.0
1.00	0.0	0.0	0.7	0.0			0.2	99.9
1.50	0.0	0.0	0.0	0.0			0.0	100.0
2.00	0.0	0.6	0.0	0.3	0.6		0.4	99.9
3.00	0.0	0.6	1.3	0.0	0.8	1.3	0.8	99.8

Waves of 15 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Directions
Direction = 15 Deg, Depth = 1 Ft   Overall BRF, %: 97.9
February/March 86

Period (Sec)	Theory Direction (Deg)	S=1" Meas (Deg)	S=3" Meas (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	S=11" Meas (Deg)	Meas Ave (Deg)	BRF (%)
0.75	15.6	15.4	15.4				15.4	98.7
1.00	14.5	14.6	14.6				14.6	99.3
1.50	14.9	15.9	16.0	15.9			15.9	93.1
2.00	14.9	16.5	13.2	15.2	15.2		15.0	99.2
3.00	14.9	14.3	15.3	15.0	15.5		15.0	99.2

(Continued)

Table 18. (Continued)

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Directions
Direction = 30 Deg, Depth = 1 Ft Overall BRF, %: 97.2
February/March 86

Period (Sec)	Theory Direction (Deg)	S=1" Meas (Deg)	S=3" Meas (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	S=11" Meas (Deg)	Meas Ave (Deg)	BRF (%)
0.75	28.0	29.6					29.6	94.3
1.00	30.2	30.2	31.8				31.0	97.4
1.50	31.0	31.5	30.7	29.9			30.7	99.0
2.00	30.9	32.3	30.5	33.0	32.3		32.0	96.4
3.00	30.3	34.1	28.9	29.9	30.0	30.4	30.7	98.8

Waves of 45 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Directions
Direction = 45 Deg, Depth = 1 Ft Overall BRF, %: 98.8
February/March 86

Period (Sec)	Theory Direction (Deg)	S=1" Meas (Deg)	S=3" Meas (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	S=11" Meas (Deg)	Meas Ave (Deg)	BRF (%)
0.75	38.8	38.8					38.8	100.0
1.00	48.9	51.1	48.2				49.7	98.5
1.50	47.4	47.0	47.6	48.3			47.6	99.5
2.00	45.9	44.2	44.2	46.6			45.0	98.0
3.00	43.9	43.7	44.1	45.1	45.9	44.6	44.7	98.2

(Continued)

Table 18. (Concluded)

Waves of 60 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured vs. Theoretical Wave Directions
Direction = 60 Deg, Depth = 1 Ft Overall BRF, %: 98.4
February/March 86

Period (Sec)	Theory Direction (Deg)	S=1" Meas (Deg)	S=3" Meas (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	S=11" Meas (Deg)	Meas Ave (Deg)	BRF (%)
0.75	38.8	38.8					38.8	100.0
1.00	48.9	49.1	49.1				49.1	99.6
1.50	59.2	59.6	59.7				59.7	99.2
2.00	63.8	62.0	62.8				62.4	97.8
3.00	58.5	54.5	57.3	58.8	52.0		55.7	95.1

(Sheet 3 of 3)

Table 19

Measured Average Versus Theoretical Wave Direction for All Directions

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Measured Average vs. Theoretical Wave Directions
Depth = 1 Ft — **Overall BRF, %: 98.81**
February/March 86

Period (Sec)	Max Direction Angle (Deg)	# Req'd Paddles	Direction = 0 Meas (Deg)	Direction = 0 Theory (Deg)	Direction = 15 Meas (Deg)	Direction = 15 Theory (Deg)	Direction = 30 Meas (Deg)	Direction = 30 Theory (Deg)	Direction = 45 Meas (Deg)	Direction = 45 Theory (Deg)	Direction = 60 Meas (Deg)	Direction = 60 Theory (Deg)
0.75	38.8	3	0.0	0.0	15.4	15.6	29.6	28.0	38.8	38.8	38.8	38.8
1.00	48.9	4	0.2	0.0	14.6	14.5	31.0	30.2	49.7	48.9	49.1	48.9
1.50	59.2	6	0.0	0.0	15.9	14.9	30.7	31.0	47.6	47.4	59.7	59.2
2.00	63.8	8	0.4	0.0	15.0	14.9	32.0	30.9	45.0	45.9	62.4	63.8
3.00	67.5	12	0.8	0.0	15.0	14.9	30.7	30.3	44.7	43.9	55.7	58.5
BRF, %:			99.6		98.5		97.6		99.6		98.7	

Table 20

Wave Direction Verification Tests

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Direction Tests: Measured vs. Theoretical Wave Direction
Desired Direction, 60 Deg
February/March 86

Period (Sec)	Theory Direction (Deg)	S=3" Meas (Deg)	BRF (%)
1.50	50.3	52.9	94.8
1.50	59.2	59.6	99.3
1.50	69.6	70.2	99.1

Overall BRF, %: 97.0

Table 21

Nonlinear Wave Period Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Nonlinear Measured vs. Theoretical Wave Periods
Direction = 0 Deg, Depth = 1 Ft
February/March 86

Overall BRF, %: 99.67

Period (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
1.50	1.498	1.495	1.500	1.498	99.84
2.00	1.993	1.994	1.997	1.995	99.73
3.00	3.017	3.016		3.017	99.43

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Nonlinear Measured vs. Theoretical Wave Periods
Direction = 30 Deg, Depth = 1 Ft
February/March 86

Overall BRF, %: 99.71

Period (Sec)	S=6" Meas (Sec)	S=9" Meas (Sec)	S=11" Meas (Sec)	Meas Ave (Sec)	BRF (%)
1.50	1.497	1.497	1.494	1.496	99.73
2.00	1.997	1.989	1.979	1.988	99.42
3.00	2.999	2.999		2.999	99.97

Table 22

Comparison of Linear and Nonlinear Harmonic Analysis Results

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Comparison of Harmonic Analysis
Linear vs Nonlinear Waves
Depth = 1 Ft
February/April 86

D=0			D=30		
Goda NLP	Mono	Nonlinear	Goda NLP	Mono	Nonlinear
0.172	88.0	87.1	0.201	93.6	91.7
0.187	88.1	86.7	0.217	82.2	88.7
0.242	83.9	75.4	0.280	82.6	79.9
0.280	76.2	78.5	0.326	67.7	79.7
0.342	68.2	74.4	0.420	64.2	71.1
0.363	68.5	69.9			

Table 23

Nonlinear Wave Height Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Nonlinear Measured vs. Theoretical Wave Heights
Direction = 0 Deg, Depth = 1 Ft
February/March 86 Overall BRF, %: 52.82

	S=6		S=9		S=11	
Period (Sec)	Meas (In)	BRF (%)	Meas (In)	BRF (%)	Meas (In)	BRF (%)
1.50	3.63	60.50	5.13	57.00	6.15	55.91
2.00	3.23	53.83	4.79	53.22	5.66	51.45
3.00	2.63	43.89	4.13	45.86		
BRF, %:		52.74		52.03		53.68

Notes:
1. Slight Breaking
2. All Breaking

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Nonlinear Measured vs. Theoretical Wave Heights
Direction = 30 Deg, Depth = 1 Ft
February/March 86 Overall BRF, %: 54.40

	S=6		S=9		S=11	
Period (Sec)	Meas (In)	BRF (%)	Meas (In)	BRF (%)	Meas (In)	BRF (%)
1.50	3.86	64.38	5.83	64.76	5.41	49.18
2.00	3.34	55.68	4.94	54.93	6.07	55.15
3.00	2.76	46.00	4.26	47.36		
BRF, %:		55.36		55.68		52.17

Notes:
1. Slight Breaking
2. All Breaking

Table 24

Nonlinear Wave Direction Analysis

Waves of 0 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Nonlinear Measured vs. Theoretical Wave Directions
Direction = 0 Deg, Depth = 1 Ft
February/March 86 Overall BRF, % 99.9

Period (Sec)	Theory Direction (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	S=11" Meas (Deg)	Meas Ave (Deg)	BRF (%)
1.50	0.0	0.0			0.0	100.0
2.00	0.0	0.0	0.0		0.0	100.0
3.00	0.0	0.0	0.8	0.9	0.6	99.8

Waves of 30 deg

MONOCHROMATIC PERFORMANCE TESTS IN DSWG BASIN
Nonlinear Measured vs. Theoretical Wave Directions
Direction = 30 Deg, Depth = 1 Ft
February/March 86 Overall BRF, %: 82.9

Period (Sec)	Theory Direction (Deg)	S=6" Meas (Deg)	S=9" Meas (Deg)	Meas Ave (Deg)	BRF (%)
1.50	31.0	34.0		34.0	90.3
2.00	30.9	35.6	43.2	39.4	72.5
3.00	30.3	33.2	35.9	34.6	86.0

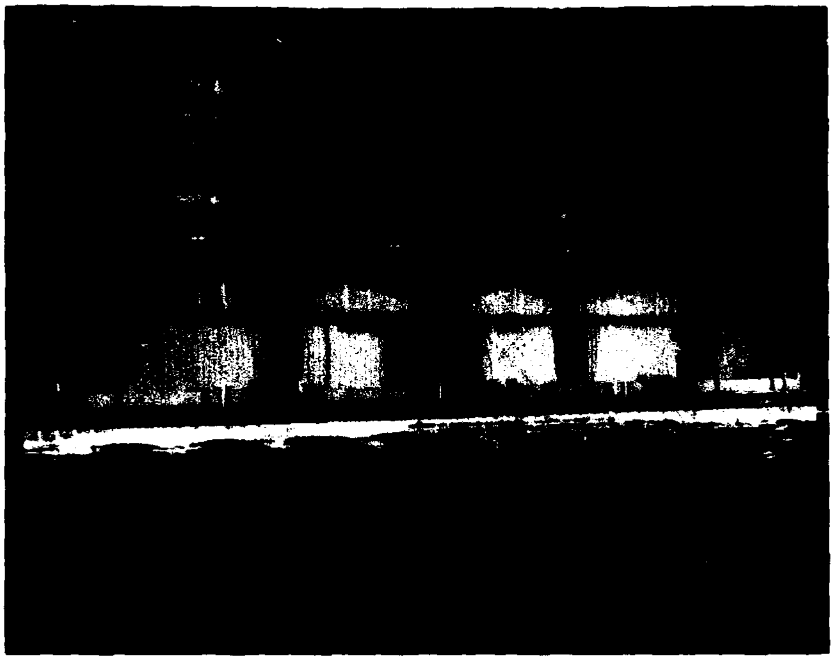


Photo 1. Directional spectral wave generator basin

Photo 2. Wave absorbers behind the DSWG

Photo 3. Beach wave absorbers opposite the DSWG

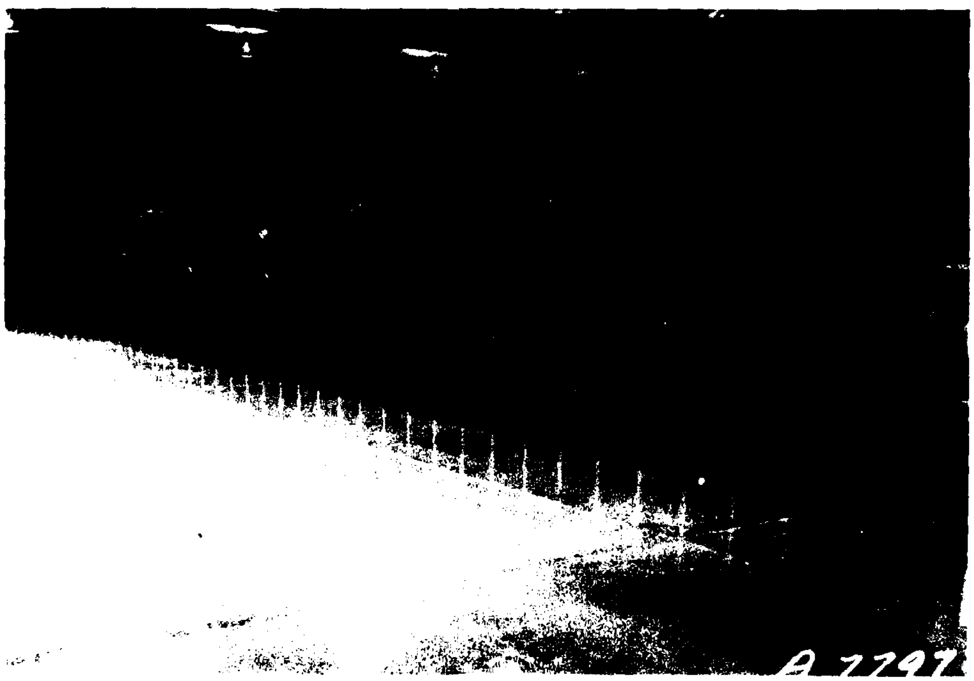
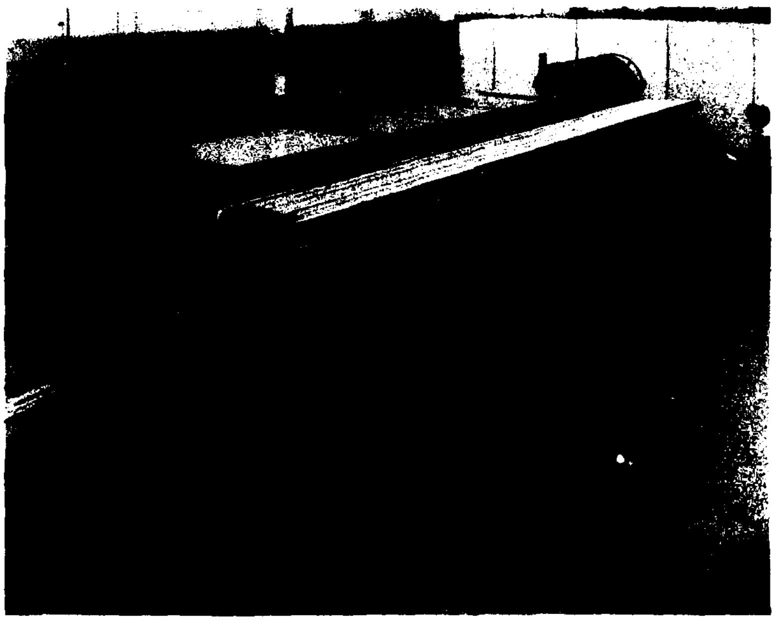


Photo 4. Directional spectral wave generator

a. Front view



b. Rear view

Photo 5. DSWG module

Photo 6. Electric motor drives

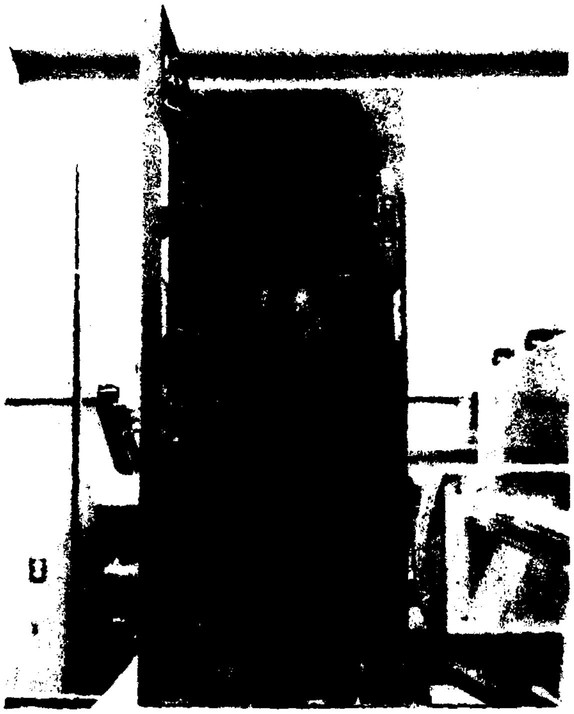


Photo 7. Power breaker box

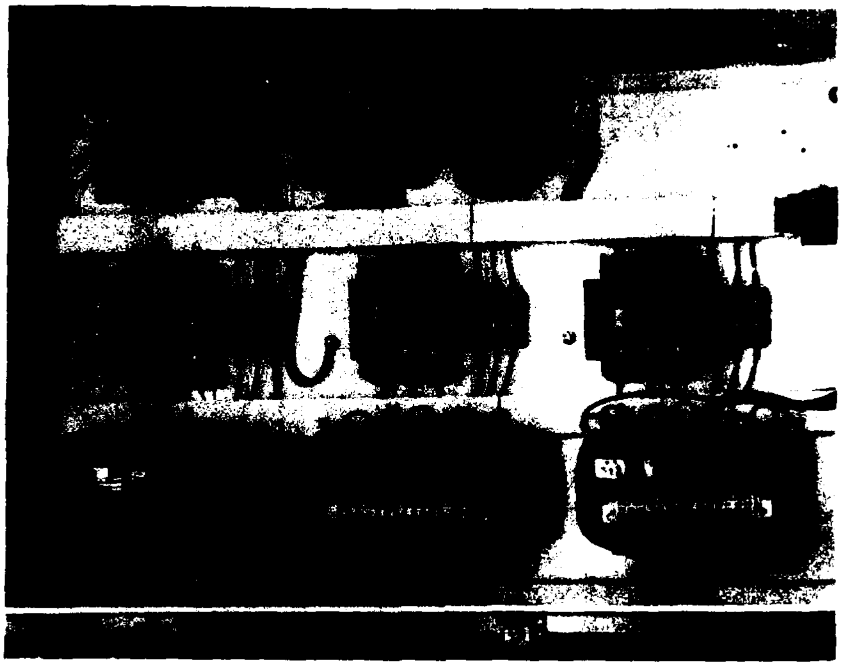


Photo 8. Main power box

Photo 9. Power and signal conditioning controllers and amplifiers

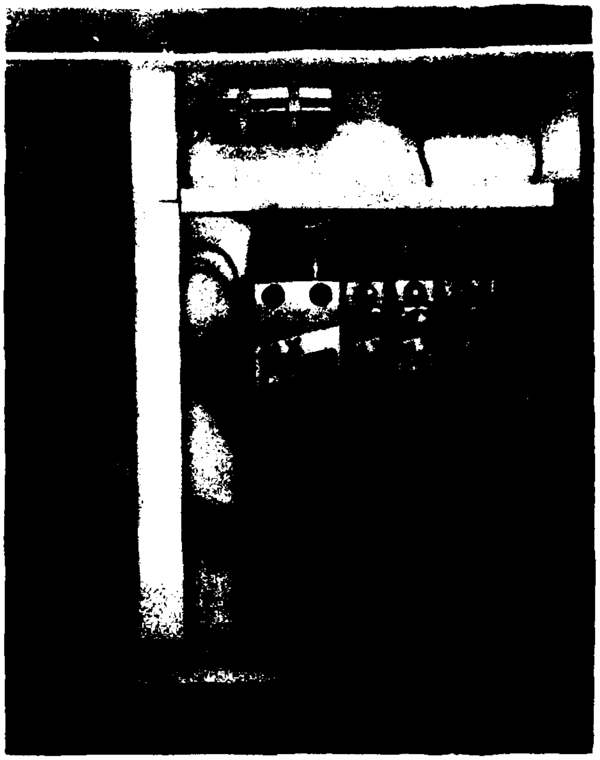


Photo 10. Close-up of Getty amplifiers and transformers

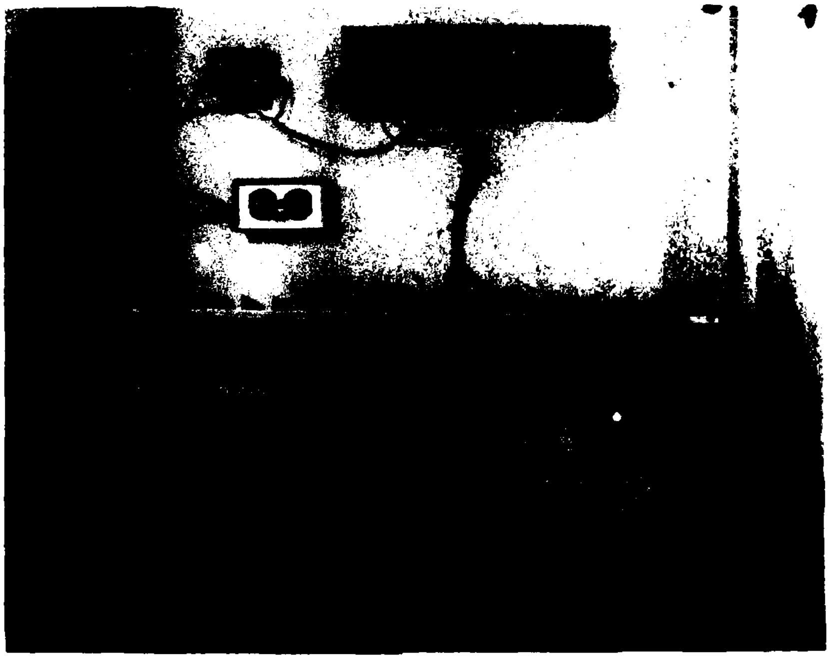
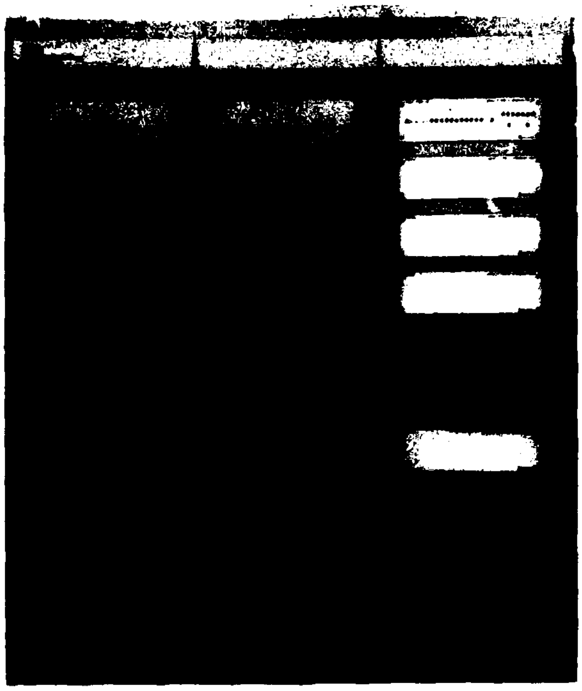


Photo 11. Control and feedback transducers



a. Front view

b. Rear view

Photo 12. Wave generator control console

Photo 13. System control panel

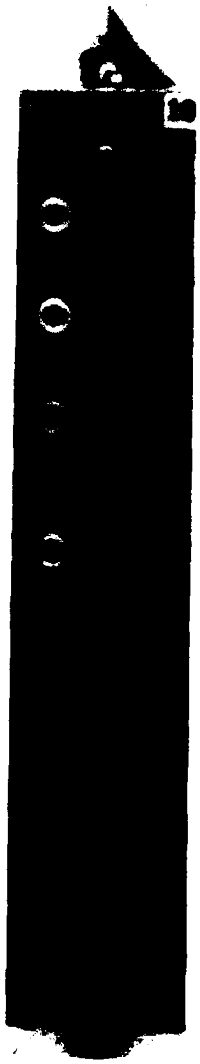
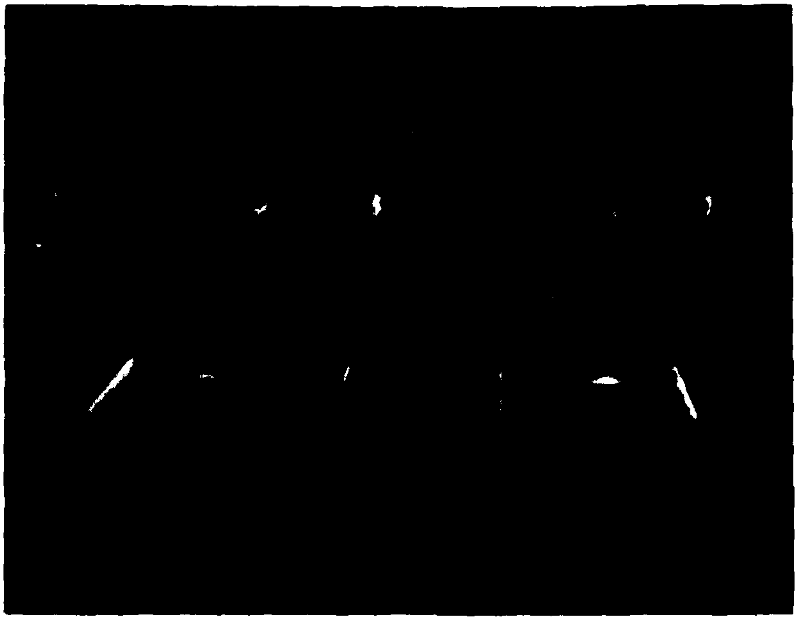


Photo 14. Servo module panel



a. Overhead view

b. Closeup view

Photo 15. Wave gage support frames

APPENDIX A: DIRECTIONAL SPECTRAL WAVE GENERATOR BASIN BATHYMETRY

BATHYMETRY FOR DIRECTIONAL SPECTRAL WAVE GENERATOR & BASIN
Corrected Values in Inches Relative to Zero-Mean
Conversion Factor: 12 in/75 ft = 0.16 in/ft

Dataset Ave:	0.00 Inches
Dataset Min:	-0.57 Inches
Dataset Max:	0.51 Inches
Dataset Std Dev:	0.18 Inches

Lengths From Wavemaker (FT)	Lengths Along Wavemaker, Ft 0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Ave	Min	Max	Std Dev
0	-0.13	-0.02	0.27	0.19	0.03	0.19	0.11	0.03	-0.13	-0.05	0.11	-0.05	0.25	0.06	-0.10	-0.33	-0.21	-0.13	0.04	-0.00	-0.33	0.27	0.16
5	0.05	0.17	0.19	0.17	0.00	0.25	0.12	0.04	-0.10	-0.23	0.04	-0.07	-0.02	-0.02	-0.12	-0.01	-0.10	-0.15	0.01	-0.00	-0.23	0.25	0.13
10	0.00	0.08	0.29	0.12	0.04	0.21	0.07	0.04	-0.07	-0.14	-0.04	-0.20	-0.12	0.01	-0.04	-0.04	0.02	-0.20	-0.01	0.00	-0.20	0.29	0.12
15	0.07	0.34	0.30	0.42	0.07	0.20	0.09	-0.03	-0.06	-0.12	-0.19	-0.20	-0.20	-0.09	-0.12	-0.04	-0.14	-0.20	-0.12	0.00	-0.20	0.42	0.19
20	0.19	0.19	0.25	0.14	0.30	0.16	0.16	-0.00	0.00	-0.24	-0.21	-0.27	-0.37	-0.24	-0.16	-0.11	0.00	0.00	-0.00	-0.00	-0.37	0.30	0.20
25	0.20	0.17	0.17	0.09	0.26	0.25	0.09	-0.07	-0.14	-0.20	0.01	-0.07	-0.15	-0.23	-0.15	-0.02	0.01	-0.12	-0.07	-0.00	-0.23	0.26	0.15
30	0.09	0.38	0.45	0.33	0.17	0.09	0.03	-0.21	-0.21	-0.19	-0.05	-0.08	-0.10	-0.13	0.05	-0.13	-0.13	-0.13	-0.15	0.00	-0.21	0.45	0.20
35	0.30	0.51	0.47	0.27	0.11	0.02	-0.09	-0.22	-0.11	0.02	-0.09	0.00	-0.00	-0.22	-0.27	-0.30	0.00	-0.14	-0.30	-0.00	-0.30	0.51	0.24
40	0.31	0.31	0.37	-0.01	0.02	-0.04	-0.01	-0.09	-0.17	-0.07	-0.19	-0.04	0.07	-0.14	-0.09	-0.17	-0.17	-0.04	0.07	0.00	-0.19	0.37	0.16
45	0.04	0.45	0.40	0.13	0.13	-0.17	-0.11	-0.03	-0.14	-0.24	-0.27	0.02	0.05	-0.11	-0.08	-0.19	-0.11	-0.08	-0.17	0.00	-0.27	0.45	0.22
50	0.33	0.28	0.12	-0.25	-0.10	-0.07	0.12	-0.23	-0.10	-0.09	0.15	-0.13	0.04	-0.09	-0.07	0.07	-0.02	-0.01	0.07	-0.00	-0.23	0.33	0.15
55	0.16	0.24	0.03	-0.00	-0.02	0.09	0.09	-0.00	-0.02	-0.16	-0.02	0.16	-0.00	-0.00	0.04	0.01	-0.16	-0.24	-0.00	-0.00	-0.24	0.24	0.12
60	0.23	0.10	0.02	-0.01	0.03	0.10	0.03	0.18	-0.06	-0.22	-0.01	0.03	0.00	-0.14	0.10	-0.06	-0.09	-0.14	-0.06	0.00	-0.22	0.23	0.11
65	-0.07	-0.21	-0.05	0.06	0.15	0.07	0.30	0.28	0.20	-0.12	-0.05	0.04	0.11	0.03	-0.05	-0.05	-0.13	-0.37	-0.13	0.00	-0.37	0.30	0.16
70	-0.05	-0.34	-0.25	0.11	0.30	0.27	0.22	0.30	0.20	-0.02	0.15	0.14	0.15	0.14	-0.10	-0.02	-0.57	-0.53	-0.26	-0.00	-0.57	0.38	0.27
Average:	0.14	0.17	0.20	0.12	0.10	0.11	0.00	-0.00	-0.06	-0.14	-0.04	-0.04	-0.04	-0.08	-0.08	-0.09	-0.12	-0.16	-0.07				
Min:	-0.13	-0.34	-0.25	-0.23	-0.10	-0.17	-0.11	-0.23	-0.21	-0.24	-0.27	-0.27	-0.37	-0.24	-0.27	-0.33	-0.57	-0.53	-0.30				
Max:	0.04	0.51	0.47	0.42	0.30	0.27	0.30	0.30	0.20	0.02	0.15	0.16	0.25	0.14	0.10	0.07	0.00	0.00	0.07				
Std Dev:	0.16	0.23	0.20	0.15	0.14	0.12	0.10	0.16	0.14	0.08	0.12	0.12	0.15	0.11	0.09	0.11	0.15	0.15	0.11				

APPENDIX B: THEORETICAL PREDICTIONS

Command File for Program

MONOSUMMARY

```
$ SET VERIFY
$ ON ERROR THEN GOTO EXIT
$ R MONOSUMMARY1
2
5
0.,15.,30.,45.,60.
5
1.,3.,6.,9.,11.
5
.75,1.,1.5,2.,3.
1.
30
0
134
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986
M
1
0
$ PRINT SUMMARY.OUT
$ EXIT:
$ SET NOVERIFY
```

Tabular Output for Program MONOSUMMARY

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 0.00
WAVE GENERATOR STROKE, INCHES = 1.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M11120	0.75	2.82	3.75	2.07	0.00	0.00	0.63	2.23	1.77	1.77	1.77	3.30	0.052	0.056	14.5	64.7
M11130	1.00	4.52	4.52	3.04	0.00	0.00	0.63	1.39	1.31	1.31	1.31	4.79	0.024	0.035	9.5	44.0
M11150	1.50	7.73	5.16	4.29	0.00	0.00	0.63	0.81	0.81	0.81	0.81	6.23	0.009	0.029	7.0	31.2
M11160	2.00	10.77	5.38	4.86	0.00	0.00	0.63	0.58	0.58	0.58	0.58	6.79	0.005	0.031	6.2	27.6
M11180	3.00	16.63	5.54	5.29	0.00	0.00	0.63	0.38	0.38	0.38	0.38	7.20	0.002	0.040	5.7	25.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 0.00
WAVE GENERATOR STROKE, INCHES = 3.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M11220	0.75	2.82	3.75	2.07	0.00	0.00	0.63	2.23	1.77	5.32	5.32	3.30	0.157	0.165	14.5	64.7
M11230	1.00	4.52	4.52	3.04	0.00	0.00	0.63	1.39	1.31	3.94	3.94	4.79	0.073	0.105	9.5	44.0
M11250	1.50	7.73	5.16	4.29	0.00	0.00	0.63	0.81	0.81	2.42	2.42	6.23	0.026	0.086	7.0	31.2
M11260	2.00	10.77	5.38	4.86	0.00	0.00	0.63	0.58	0.58	1.75	1.75	6.79	0.014	0.093	6.2	27.6
M11280	3.00	16.63	5.54	5.29	0.00	0.00	0.63	0.38	0.38	1.13	1.13	7.20	0.006	0.121	5.7	25.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 0.00
WAVE GENERATOR STROKE, INCHES = 6.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M11320	0.75	2.82	3.75	2.07	0.00	0.00	0.63	2.23	1.77	10.63	10.63	3.30	0.315	0.337	14.5	64.7
M11330	1.00	4.52	4.52	3.04	0.00	0.00	0.63	1.39	1.31	7.87	7.87	4.79	0.145	0.211	9.5	44.0
M11350	1.50	7.73	5.16	4.29	0.00	0.00	0.63	0.81	0.81	4.83	4.83	6.23	0.052	0.172	7.0	31.2
M11360	2.00	10.77	5.38	4.86	0.00	0.00	0.63	0.58	0.58	3.49	3.49	6.79	0.027	0.187	6.2	27.6
M11380	3.00	16.63	5.54	5.29	0.00	0.00	0.63	0.38	0.38	2.27	2.27	7.20	0.011	0.242	5.7	25.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 0.00
WAVE GENERATOR STROKE, INCHES = 9.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(O) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M11420	0.75	2.82	3.75	2.07	0.00	0.00	0.63	2.23	1.77	15.95	15.95	3.30	0.472	0.506	14.5	64.7
M11430	1.00	4.52	4.52	3.04	0.00	0.00	0.63	1.39	1.31	11.81	11.81	4.79	0.218	0.316	9.9	44.0
M11450	1.50	7.73	5.16	4.29	0.00	0.00	0.63	0.81	0.81	7.25	7.25	6.23	0.078	0.259	7.0	31.2
M11460	2.00	10.77	5.38	4.86	0.00	0.00	0.63	0.58	0.58	5.24	5.24	6.79	0.041	0.280	6.2	27.5
M11480	3.00	16.63	5.54	5.29	0.00	0.00	0.63	0.38	0.38	3.40	3.40	7.20	0.017	0.363	5.7	25.7

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 0.00
WAVE GENERATOR STROKE, INCHES = 11.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(O) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M11520	0.75	2.82	3.75	2.07	0.00	0.00	0.63	2.23	1.77	19.49	19.49	3.30	0.577	0.618	14.5	64.7
M11530	1.00	4.52	4.52	3.04	0.00	0.00	0.63	1.39	1.31	14.43	14.43	4.79	0.266	0.386	9.9	44.0
M11550	1.50	7.73	5.16	4.29	0.00	0.00	0.63	0.81	0.81	8.86	8.86	6.23	0.095	0.316	7.0	31.2
M11560	2.00	10.77	5.38	4.86	0.00	0.00	0.63	0.58	0.58	6.40	6.40	6.79	0.050	0.342	6.2	27.6
M11580	3.00	16.63	5.54	5.29	0.00	0.00	0.63	0.38	0.38	4.16	4.16	7.20	0.021	0.443	5.7	25.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 15.00
WAVE GENERATOR STROKE, INCHES = 1.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(O) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M14120	0.75	2.82	3.75	2.07	51.43	15.56	0.69	2.23	1.77	1.77	1.84	3.30	0.054	0.056	15.0	67.2
M14130	1.00	4.52	4.52	3.04	30.00	14.55	0.68	1.39	1.31	1.31	1.36	4.79	0.025	0.036	10.2	45.5
M14150	1.50	7.73	5.16	4.29	18.00	14.94	0.69	0.81	0.81	0.81	0.83	6.23	0.009	0.030	7.2	32.3
M14160	2.00	10.77	5.38	4.86	12.86	14.85	0.69	0.58	0.58	0.58	0.60	6.79	0.005	0.032	6.4	28.5
M14180	3.00	16.63	5.54	5.29	8.37	14.74	0.69	0.38	0.38	0.38	0.39	7.20	0.002	0.042	5.9	26.2

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	15.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	3.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M14220	0.75	2.82	3.75	2.07	51.43	15.56	0.69	2.23	1.77	5.32	5.52	3.30	0.163	0.175	15.0	67.2
M14230	1.00	4.52	4.52	3.04	30.00	14.55	0.68	1.39	1.31	3.94	4.07	4.79	0.075	0.105	10.2	45.5
M14250	1.50	7.73	5.16	4.29	18.00	14.94	0.69	0.81	0.81	2.42	2.50	6.23	0.027	0.089	7.2	32.3
M14260	2.00	10.77	5.38	4.86	12.86	14.85	0.69	0.58	0.58	1.75	1.81	6.79	0.014	0.097	6.4	28.5
M14280	3.00	16.63	5.54	5.29	8.37	14.94	0.69	0.38	0.38	1.13	1.17	7.20	0.006	0.125	5.9	26.2

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	15.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	6.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M14320	0.75	2.82	3.75	2.07	51.43	15.56	0.69	2.23	1.77	10.63	11.04	3.30	0.327	0.350	15.0	67.2
M14330	1.00	4.52	4.52	3.04	30.00	14.55	0.68	1.39	1.31	7.87	8.13	4.79	0.150	0.218	10.2	45.5
M14350	1.50	7.73	5.16	4.29	18.00	14.94	0.69	0.81	0.81	4.83	5.00	6.23	0.054	0.176	7.2	32.3
M14360	2.00	10.77	5.38	4.86	12.86	14.85	0.69	0.58	0.58	3.49	3.61	6.79	0.028	0.193	6.4	28.5
M14380	3.00	16.63	5.54	5.29	8.37	14.94	0.69	0.36	0.36	2.27	2.35	7.20	0.012	0.250	5.9	26.2

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	15.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	9.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M14420	0.75	2.82	3.75	2.07	51.43	15.56	0.69	2.23	1.77	15.95	16.55	3.30	0.490	0.525	15.0	67.2
M14430	1.00	4.52	4.52	3.04	30.00	14.55	0.68	1.39	1.31	11.81	12.20	4.79	0.225	0.326	10.2	45.5
M14450	1.50	7.73	5.16	4.29	18.00	14.94	0.69	0.81	0.81	7.25	7.50	6.23	0.081	0.268	7.2	32.3
M14460	2.00	10.77	5.38	4.86	12.86	14.85	0.69	0.58	0.58	5.24	5.42	6.79	0.042	0.250	6.4	28.5
M14480	3.00	16.63	5.54	5.29	8.37	14.94	0.69	0.36	0.36	3.40	3.52	7.20	0.018	0.375	5.9	26.2

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 15.00
WAVE GENERATOR STROKE, INCHES = 11.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M14520	0.75	2.82	3.75	2.07	51.43	15.56	0.69	2.23	1.77	19.45	20.23	3.30	0.599	0.642	15.0	67.2
M14530	1.00	4.52	4.52	3.04	30.00	14.55	0.68	1.39	1.31	14.43	14.91	4.79	0.275	0.399	10.2	45.5
M14550	1.50	7.73	5.16	4.29	18.00	14.94	0.69	0.81	0.81	8.86	9.17	6.23	0.099	0.327	7.2	32.3
M14560	2.00	10.77	5.38	4.86	12.86	14.85	0.69	0.58	0.58	6.40	6.63	6.79	0.051	0.354	6.4	28.5
M14580	3.00	16.63	5.54	5.29	8.37	14.94	0.69	0.38	0.38	4.16	4.30	7.20	0.022	0.459	5.9	26.2

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 30.00
WAVE GENERATOR STROKE, INCHES = 1.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M17120	0.75	2.82	3.75	2.07	90.00	27.99	0.73	2.23	1.77	1.77	2.01	3.30	0.059	0.064	16.4	73.3
M17130	1.00	4.52	4.52	3.04	60.00	30.15	0.73	1.39	1.31	1.31	1.52	4.79	0.028	0.041	11.4	50.5
M17150	1.50	7.73	5.16	4.29	36.00	31.04	0.74	0.81	0.81	0.81	0.94	6.23	0.010	0.034	8.2	36.4
M17160	2.00	10.77	5.38	4.86	25.71	30.84	0.74	0.58	0.58	0.58	0.68	6.79	0.005	0.036	7.2	32.1
M17180	3.00	16.63	5.54	5.29	16.36	30.25	0.73	0.38	0.38	0.38	0.44	7.20	0.002	0.047	6.6	29.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 30.00
WAVE GENERATOR STROKE, INCHES = 3.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M17220	0.75	2.82	3.75	2.07	90.00	27.99	0.73	2.23	1.77	5.32	6.02	3.30	0.178	0.191	16.4	73.3
M17230	1.00	4.52	4.52	3.04	60.00	30.15	0.73	1.39	1.31	3.94	4.55	4.79	0.084	0.122	11.4	50.5
M17250	1.50	7.73	5.16	4.29	36.00	31.04	0.74	0.81	0.81	2.42	2.82	6.23	0.030	0.101	8.2	36.4
M17260	2.00	10.77	5.38	4.86	25.71	30.84	0.74	0.58	0.58	1.75	2.03	6.79	0.016	0.109	7.2	32.1
M17280	3.00	16.63	5.54	5.29	16.36	30.25	0.73	0.38	0.38	1.13	1.31	7.20	0.007	0.140	6.6	29.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	30.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	6.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M17320	0.75	2.82	3.75	2.07	90.00	27.99	0.73	2.23	1.77	10.63	12.04	3.30	0.356	0.382	16.4	73.3
M17330	1.00	4.52	4.52	3.04	60.00	30.15	0.73	1.39	1.31	7.87	9.10	4.79	0.168	0.244	11.4	50.9
M17350	1.50	7.73	5.16	4.29	36.00	31.04	0.74	0.81	0.81	4.83	5.64	6.23	0.061	0.201	8.2	36.4
M17360	2.00	10.77	5.38	4.86	25.71	30.84	0.74	0.58	0.58	3.49	4.07	6.79	0.031	0.217	7.2	32.1
M17380	3.00	16.63	5.54	5.29	16.36	30.25	0.73	0.38	0.38	2.27	2.62	7.20	0.013	0.280	6.6	29.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	30.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	9.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M17420	0.75	2.82	3.75	2.07	90.00	27.99	0.73	2.23	1.77	15.95	18.06	3.30	0.534	0.573	16.4	73.3
M17430	1.00	4.52	4.52	3.04	60.00	30.15	0.73	1.39	1.31	11.81	13.65	4.79	0.252	0.365	11.4	50.9
M17450	1.50	7.73	5.16	4.29	36.00	31.04	0.74	0.81	0.81	7.25	8.46	6.23	0.091	0.302	8.2	36.4
M17460	2.00	10.77	5.38	4.86	25.71	30.84	0.74	0.58	0.58	5.24	6.10	6.79	0.047	0.326	7.2	32.1
M17480	3.00	16.63	5.54	5.29	16.36	30.25	0.73	0.38	0.38	3.40	3.94	7.20	0.020	0.420	6.6	29.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	30.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	11.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M17520	0.75	2.82	3.75	2.07	90.00	27.99	0.73	2.23	1.77	19.49	22.07	3.30	0.653	0.700	16.4	73.3
M17530	1.00	4.52	4.52	3.04	60.00	30.15	0.73	1.39	1.31	14.43	16.69	4.79	0.308	0.447	11.4	50.9
M17550	1.50	7.73	5.16	4.29	36.00	31.04	0.74	0.81	0.81	8.66	10.34	6.23	0.111	0.369	8.2	36.4
M17560	2.00	10.77	5.38	4.86	25.71	30.84	0.74	0.58	0.58	6.40	7.46	6.79	0.058	0.398	7.2	32.1
M17580	3.00	16.63	5.54	5.29	16.36	30.25	0.73	0.36	0.36	4.16	4.81	7.20	0.024	0.513	6.6	29.3

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	45.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	1.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M18120	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	1.77	2.27	3.30	0.067	0.072	18.6	83.0
M18130	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	1.31	2.00	4.79	0.037	0.053	15.0	67.0
M18150	1.50	7.73	5.16	4.29	51.43	47.44	0.78	0.81	0.81	0.81	1.19	6.23	0.013	0.042	10.3	46.1
M18160	2.00	10.77	5.38	4.86	36.00	45.87	0.77	0.58	0.58	0.58	0.84	6.79	0.006	0.045	8.9	39.6
M18180	3.00	16.63	5.54	5.29	22.50	43.85	0.77	0.38	0.38	0.38	0.52	7.20	0.003	0.056	7.9	35.1

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	45.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	3.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M18220	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	5.32	6.82	3.30	0.202	0.216	18.6	83.0
M18230	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	3.94	5.99	4.79	0.110	0.160	15.0	67.0
M18250	1.50	7.73	5.16	4.29	51.43	47.44	0.78	0.81	0.81	2.42	3.57	6.23	0.038	0.127	10.3	46.1
M18260	2.00	10.77	5.38	4.86	36.00	45.87	0.77	0.58	0.58	1.75	2.51	6.79	0.019	0.134	8.9	39.6
M18280	3.00	16.63	5.54	5.29	22.50	43.85	0.77	0.38	0.38	1.13	1.57	7.20	0.008	0.168	7.9	35.1

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG =	45.00	DISTANCE TO BACK GAGE ROW, FT =	30.00
WAVE GENERATOR STROKE, INCHES =	6.00	TRIP DISTANCE TO BACK GAGE ROW, FT =	134.00
WATER DEPTH, FT =	1.00	# WAVES PRIOR TO SAMPLING =	0
MAX BREAK HEIGHT, H/D=0.78, IN =	9.36		

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M18320	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	10.63	13.63	3.30	0.403	0.432	18.6	83.0
M18330	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	7.87	11.97	4.79	0.221	0.320	15.0	67.0
M18350	1.50	7.73	5.16	4.29	51.43	47.44	0.78	0.81	0.81	4.63	7.15	6.23	0.077	0.255	10.3	46.1
M18360	2.00	10.77	5.38	4.86	36.00	45.87	0.77	0.58	0.58	3.49	5.02	6.79	0.039	0.268	8.9	39.6
M18380	3.00	16.63	5.54	5.29	22.50	43.85	0.77	0.38	0.38	2.27	3.14	7.20	0.016	0.335	7.9	35.1

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 45.00
WAVE GENERATOR STROKE, INCHES = 9.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M18420	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	15.95	20.45	3.30	0.605	0.648	18.6	83.0
M18430	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	11.61	17.96	4.79	0.331	0.481	15.0	67.0
M18450	1.50	7.73	5.16	4.29	51.43	47.44	0.78	0.81	0.81	7.25	10.72	6.23	0.115	0.382	10.3	46.1
M18460	2.00	10.77	5.38	4.86	36.00	45.87	0.77	0.58	0.58	5.24	7.53	6.79	0.058	0.402	8.9	35.6
M18480	3.00	16.63	5.54	5.29	22.50	43.85	0.77	0.38	0.38	3.40	4.71	7.20	0.024	0.507	7.9	35.1

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 45.00
WAVE GENERATOR STROKE, INCHES = 11.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M18520	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	19.49	24.99	3.30	0.740	0.792	18.6	83.0
M18530	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	14.43	21.95	4.79	0.405	0.587	15.0	67.0
M18550	1.50	7.73	5.16	4.29	51.43	47.44	0.78	0.81	0.81	8.86	13.10	6.23	0.141	0.467	10.3	46.1
M18560	2.00	10.77	5.38	4.86	36.00	45.87	0.77	0.58	0.58	6.40	9.20	6.79	0.071	0.491	8.9	35.6
M18580	3.00	16.63	5.54	5.29	22.50	43.85	0.77	0.38	0.38	4.16	5.76	7.20	0.029	0.614	7.9	35.1

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 60.00
WAVE GENERATOR STROKE, INCHES = 1.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M10120	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	1.77	2.27	3.30	0.067	0.072	16.6	63.0
M10130	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	1.31	2.00	4.79	0.037	0.053	15.0	67.0
M10150	1.50	7.73	5.16	4.29	60.00	59.24	0.80	0.81	0.81	0.81	1.58	6.23	0.017	0.056	13.7	61.0
M10160	2.00	10.77	5.38	4.86	45.00	63.79	0.81	0.58	0.58	0.58	1.32	6.79	0.010	0.070	14.0	62.5
M10180	3.00	16.63	5.54	5.29	27.69	58.50	0.80	0.38	0.38	0.38	0.72	7.20	0.004	0.077	10.6	48.4

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 60.00
WAVE GENERATOR STROKE, INCHES = 3.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M10220	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	5.32	6.82	3.30	0.282	0.216	18.6	63.0
M10230	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	3.94	5.99	4.79	0.110	0.160	15.0	67.0
M10250	1.50	7.73	5.16	4.29	60.00	59.24	0.80	0.81	0.81	2.42	4.73	6.23	0.051	0.169	13.7	61.0
M10260	2.00	10.77	5.38	4.86	45.00	63.79	0.81	0.58	0.58	1.75	3.95	6.79	0.031	0.211	14.0	62.5
M10280	3.00	16.63	5.54	5.29	27.69	58.50	0.80	0.38	0.38	1.13	2.17	7.20	0.011	0.231	10.8	48.4

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 60.00
WAVE GENERATOR STROKE, INCHES = 6.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M10320	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	10.63	13.63	3.30	0.403	0.432	18.6	63.0
M10330	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	7.87	11.97	4.79	0.221	0.320	15.0	67.0
M10350	1.50	7.73	5.16	4.29	60.00	59.24	0.80	0.81	0.81	4.83	9.45	6.23	0.102	0.337	13.7	61.0
M10360	2.00	10.77	5.38	4.86	45.00	63.79	0.81	0.58	0.58	3.49	7.91	6.79	0.061	0.422	14.0	62.5
M10380	3.00	16.63	5.54	5.29	27.69	58.50	0.80	0.38	0.38	2.27	4.34	7.20	0.022	0.463	10.8	48.4

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 60.00
WAVE GENERATOR STROKE, INCHES = 9.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M10420	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	15.95	20.45	3.30	0.605	0.648	18.6	83.0
M10430	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	11.81	17.96	4.79	0.331	0.481	15.0	67.0
M10450	1.50	7.73	5.16	4.29	60.00	59.24	0.80	0.81	0.81	7.25	14.18	6.23	0.153	0.586	13.7	61.0
M10460	2.00	10.77	5.38	4.86	45.00	63.79	0.81	0.58	0.58	5.24	11.86	6.79	0.092	0.634	14.0	62.5
M10480	3.00	16.63	5.54	5.29	27.69	58.50	0.80	0.38	0.38	3.40	6.51	7.20	0.033	0.654	10.8	48.4

MONOCHROMATIC WAVE SUMMARY
MONOCHROMATIC PERFORMANCE TESTS
JANUARY TO MARCH 1986

ANGLE OF WAVE PROPAGATION, DEG = 60.00
WAVE GENERATOR STROKE, INCHES = 11.00
WATER DEPTH, FT = 1.00
MAX BREAK HEIGHT, H/D=0.78, IN = 9.36

DISTANCE TO BACK GAGE ROW, FT = 30.00
TRIP DISTANCE TO BACK GAGE ROW, FT = 134.00
WAVES PRIOR TO SAMPLING = 0

RUN #	T (SEC)	L (FT)	SPEED (FPS)	GROUP (FPS)	OFFSET (DEG)	ANGLE (DEG)	TMIN (SEC)	KH	H/S	H(0) (IN)	H(TH) (IN)	HMAX (IN)	H/L	NL PARAM	TIME1 (SEC)	TIME2 (SEC)
M10520	0.75	2.82	3.75	2.07	120.00	38.74	0.76	2.23	1.77	19.49	24.99	3.30	0.740	0.792	18.6	83.0
M10530	1.00	4.52	4.52	3.04	90.00	48.89	0.78	1.39	1.31	14.43	21.95	4.79	0.405	0.587	15.0	67.0
M10550	1.50	7.73	5.16	4.29	60.00	59.24	0.80	0.81	0.81	8.86	17.33	6.23	0.187	0.618	13.7	61.0
M10560	2.00	10.77	5.38	4.86	45.00	63.79	0.81	0.58	0.58	6.40	14.50	6.79	0.112	0.774	14.0	62.5
M10580	3.00	16.63	5.54	5.29	27.69	58.50	0.80	0.38	0.38	4.16	7.95	7.20	0.040	0.848	10.8	48.4

APPENDIX C: CONTROL SIGNAL GENERATION

Command File for COMPONM

```
$ON CONTROL_Y THEN GOTO EOFIT
$DEFINE/USER_MODE SYS$INPUT SYS$COMMAND:
$R [OLDMCCLEAVE]COMPONM
$EOFIT: DEFINE/USER_MODE SYS$INPUT SYS$COMMAND:
$ R TWOEOF
$ON ERROR THEN GOTO DIS2
$DISM MSA0:
$DIS2: DISM MSB0:
```

Command File for COMPONC4

```
$ON CONTROL_Y THEN GOTO EOFIT
$DEFINE/USER_MODE SYS$INPUT SYS$COMMAND:
$R [OLDMCCLEAVE]COMPONC4
$EOFIT: DEFINE/USER_MODE SYS$INPUT SYS$COMMAND:
$ R TWOEOF
$ON ERROR THEN GOTO DIS2
$DISM MSA0:
$DIS2: DISM MSB0:
```

Table C1

Procedure for Program COMPONM

Sinusoidal Control Signal Generation

Step	Description	Input	Comments
1	Log on User ID: Password:	 Hampton	 Get current password from Hampton
2	Change directory	SDOM	Set default to [OLDMCCLEAVE] (Note: Procedure used during these tests, since changed)
3	Activate command procedure	@MRO	Make sure tape not mounted as program mounts
4	Tape drive	0	0=MSAO:, 1=MSBO:
5	Control signal filename	M17360	Must be 6 characters long
6	Old or new tape	Old	OLD=Files already on tape, searches for double end-of-file (EOF) and removes in preparation for writing new file NEW=No files currently on tape, writes new file @ beginning
7	Old parameter file	Y	Y=Reads from FOR013.DAT information from previous use N=Use if no previous file exists or previously used for COMPONC4
8	Change # components	N	N=Uses current value for # components Y=Queries user for # of components to be combined
9	Change periods	N	N=Leaves unchanged Y=Queries user for periods for each component specified, can be identical among components

(Continued)

Table C1 (Concluded)

Step	Description	Input	Comments
10	Change phases	N	N=Leaves unchanged Y=Queries user for phases for each component specified, usually zero
11	Change peak-to-peak displacement	Y	Y=Queries user for stroke, in. N=Leaves unchanged
	Displacement	6.0	
12	Change paddle offset angle	N	N=Leaves unchanged Y=Queries user for offset angle necessary to generate wave angle
13	Parameters menu	L	L=Lists specifications for each component
14	Parameters menu	Q	Q=Begins writing control signal to tape, usually run 2 min. Enter CTRL C to terminate
15	Write EOF's	Y	Y=Writes 2 EOF's @ end of tape N=Use only if filename not specified
16	Log off	LO	

Table C2

Procedure for Program COMPONC4

Cnoidal Control Signal Generation

Step	Description	Input	Comments
1	Log on User ID: Password:	 Hampton	 Get current password from Hampton
2	Change directory	SDOM	Set default to [OLDMCCLEAVE] (Note: Procedure used during these tests, since changed)
3	Activate command procedure	@NRO	Make sure tape not mounted as program mounts
4	Tape drive	0	0=MSA0:, 1=MSB0:
5	Control signal filename	MN7360	Must be 6 characters long
6	Old or new tape	Old	OLD=Files already on tape, searches for double end-of-file and removes in preparation for writing new file NEW=No files currently on tape, writes new file @ beginning
7	Old parameter file	Y	Y=Reads from FOR013.DAT information from previous use N=Use if no previous file exists or previously used for COMPONM
8	Change # components	N	N=Uses current value for # components Y=Queries user for # of components to be combined
9	Depth	1.0	Enter value in feet
10	Change wavelengths	Y	Y=Queries user for wavelength for each component, input described in step 10a below N=Leaves unchanged
10a	Enter wavelength	12.45	Corresponds to 2.0 sec

(Continued)

Table C2 (Concluded)

Step	Description	Input	Comments
11	Change phases	N	N=Leaves unchanged Y=Queries user for phases for each component specified, usually zero
12	Change peak-to-peak displacement	Y	Y=Queries user for stroke, in. N=Leaves unchanged
	Displacement	6.0	
13	Change paddle offset angle	N	N=Leaves unchanged Y=Queries user for offset angle necessary to generate wave angle
14	Parameters menu	L	L=Lists specifications for each component
15	Parameters menu	Q	Q=Begins writing control signal to tape, usually run 2 min. Enter CTRL C to terminate
16	Write EOF's	Y	Y=Writes 2 EOF's @ end of tape N=Use only if filename not specified
17	Log off	LO	

APPENDIX D: WAVE GAGE CALIBRATION

Table D1

Procedure for Process IDCAL, Setup

Step	Description	Input	Comments
1	Log on		
	User ID:	Hampton	
	Password:		Get current password from Hampton
2	Type input file	T	T=Test, M=Master
3	Input filename	M1/360	Must be 6 characters long
4	Output filename	M1/360	Saves changes to same file input, new file if given different name
5	Main menu	1	1=Header 1, choose from 1 to 15, repeats when exit a Header submenu
6	Header 1 menu		Select line corresponding to input desired, repeats after each entry, enter -1 to return to main menu
	3: Run #	1	
	4: Model name	M17360	Should match step 4 above, inches
	11: Wave height	1.0	
7	Header 2 menu		Select line corresponding to input desired, repeats after each entry, enter -1 to return to main menu
	1: Sampling period	2	Sec
	2: Scans/period	100	Period * 50
	3: Records/period	100	Period * 50
	4: # Periods	6	Test duration = #1 * #4 = 12
	13: DSWG stroke	6	Same as Header 1 for wave height
	16: DAC updates/per	40	Period * 20 (Note: Actually used 200, but only good for header, so did not matter)
	18: Wave direction	30	Enter 0, 15, 30, 45, or 60 deg
8	Main menu	7	Lists rod coefficients, switches should prevent gage rod damage, enter -1 to return to main menu
9	Main menu	14	Prints all data entries including gage and rod coefficients, enter -1 to return to main menu
10	Main menu	15	Exits process and saves to file specified as output

Table D2

Procedure for Process IDCAL, Calibrating Gages

Step	Description	Input	Comments
1	Main menu	11	Selects gage calibration mode, assumes already logged on & in main menu of Process IDCAL
2	Cal range input	A	A=All gages K=Keyboard for individual gages D=Diskfile for individual gages
3	Cal range	10	10=Jordan gages 3.25=small gages
4	OK to dip	Y	Y=Begin dip of rods N=Return to Step 3
5	OK to cal	0	0=OK to wet gages for setting zero 1=abort initial dip, adjust zero on gages prior to activating w/rotary "Balance R" on instrumentation control panel, automatically prints cals on LPAO:
6	Re-do selected gages	N	N=No, usually OK Y=Yes, if necessary to recal, see Step 6a, might wipe gage rods with alcohol
6a	Gage #'s to recal	1-3, 7	Enter gage #'s as instructed
7	Main menu	15	Exits process and saves to file specified as output

Table D3

Quadratic Fit Calibration Coefficients for Small Wave Gages

Monochromatic Performance Tests in DSWG Basin

			Maximum Deviation, 10^{-5} ft											
			Gage No.											
No.	Date	Time	RD01	RD02	RD03	RD04	RD05	RD06	RD07	RD08	RD09	Min	Max	Avg
1	18 Feb	1427	181	144	170	177	265	191	166	121	179	121	265	177
2	20 Feb	1715	48	204	245	305	345	67	332	237	329	48	345	235
3	22 Feb	934	106	167	214	338	356	131	238	231	282	106	356	229
4		1700	68	84	143	295	254	102	203	130	206	68	295	165
5	23 Feb	1230	89	104	168	274	241	104	196	127	211	89	274	168
6		1600	81	122	169	265	244	144	217	147	228	81	265	180
7	25 Feb	1015	126	116	127	173	237	136	208	148	235	116	237	167
8		1900	99	79	134	185	234	115	195	146	255	79	255	160
9	27 Feb	830	169	110	148	120	188	182	201	141	171	110	201	159
10		1320	167	121	95	107	160	169	131	95	132	95	169	131
11		1900	78	87	142	150	159	111	175	127	184	78	184	135
12	4 Mar	830	22	41	48	72	86	80	113	113	129	22	129	78
13		1330	34	48	67	78	88	61	90	76	109	34	109	72
14		1930	37	51	56	72	65	51	85	81	114	37	114	68
15	6 Mar	800	72	73	90	102	117	85	101	79	122	72	122	93
16		1230	105	134	130	136	117	186	149	94	113	94	186	129
17		1920	20	35	50	55	56	45	54	62	63	20	62	49
18	8 Mar	800	26	39	41	54	62	48	58	48	46	26	62	47
19		1300	35	49	44	65	71	86	76	70	61	35	86	62
20		1600	87	97	81	49	74	51	59	40	58	40	97	66
21	9 Mar	730	39	34	39	28	60	35	28	35	39	28	60	37
22	11 Mar	830	161	169	156	174	211	161	165	174	178	156	211	172
	Averages:		84	96	116	149	168	106	147	115	157	71	186	126

Note: DSWG = Directional spectral wave generator.

Table D4

Quadratic Fit Calibration Coefficients for Jordan Wave Gages

Monochromatic Performance Tests in DSWG Basin

			Maximum Deviation, 10^{-5} ft											
			Gage No.											
No.	Date	Time	RD01	RD02	RD03	RD04	RD05	RD06	RD07	RD08	RD09	Min	Max	Avg
23	8 Apr	923	1,885	990	1,486	800	960	468	1,272	2,307	2,481	468	2,481	1,405
24	9 Apr	1109	1,402	1,092	1,542	742	622	494	1,360	2,156	1,595	494	2,156	1,223
25		1930	1,242	1,215	981	667	460	399	1,382	1,236	1,477	399	1,477	1,006
26	10 Apr	900	1,074	1,030	1,297	587	493	223	1,126	1,571	1,367	223	1,571	974
27		2048	1,469	1,305	1,415	720	462	234	1,390	1,620	1,526	234	1,620	1,127
28	11 Apr	1000	1,301	300	1,953	1,596	902	526	1,278	1,168	1,330	300	1,953	1,150
29		720	1,392	226	2,053	1,998	980	655	1,473	1,935	1,345	226	2,053	1,340
30	12 Apr	800	1,438	210	1,681	1,952	791	531	1,490	1,692	1,301	210	1,952	1,232
31		1245	1,409	298	1,783	2,040	926	589	1,402	1,525	1,268	298	2,040	1,249
32		1730	1,377	237	2,047	2,186	815	653	1,490	1,994	1,352	237	2,186	1,350
	Averages:		1,399	690	1,624	1,329	741	477	1,366	1,720	1,504	309	1,949	1,206

Note: DSWG = Directional spectral wave generator.

APPENDIX E: WAVE GENERATION AND MEASUREMENT

Table E1

Procedure for Process TAPEM2

Wave Generation and Measurement

Step	Description	Input	Comments
1	Log on User ID: Password:	 TAPEM2 VAX	 Get current password from Hampton
2	Tape drive	0	0=MSA0:, 1=MSB0:
3	Control signal filename	M17360	Must be 6 characters long & exist on tape indicated in Step 2
4	Starting delay to disk I/O, sec	26	Time after starting test before disk storage of measured data begins, includes 10-sec delay time
5	Total test length, sec	25	Total time DSWG will run and data will be stored on disk, make GT time specified in Header 2 of Process IDCAL
6	Options	S	S=Starts test E=Ends test if abort, enter positive real # for # of seconds to ramp down, normally ends automatically after time specified in Step 5 above Other options not used include: D=Change channels saved on disk or add decimation O=Graph channels on oscilloscope P=Print data on Versatec plotter

Note: DSWG = Directional spectral wave generator.

APPENDIX F: WAVE ANALYSIS

Command File for Program DISKDISK

```
$ SET VERIFY
$ SDA
$ R DISKDISK
M17360
1
$ PU WVANSDISK.COM
$ SET NOVERIFY
```

Command File for Program WVANSDISK1

```
$ SET VERIFY
$ ON ERROR THEN GOTO EXIT
$ R WVANSDISK1
-1
0
Y
Y
Y
Y
7.
2.
M17360, D=30, S=6", 6 @ T=2.00 S
1.0
M17360
$ PRINT FOR001.DAT
$ PU FOR001.DAT
$ PU [HAMPTON]DISKDISK.COM
!$ REN PARM.PLV M17360.PPLV
!$ REN VECTR1.PLV M17360.VPLV
$ PHASE2
$ EXIT:
$ SET NOVERIFY
```

Command File for Program WAVELS

```
C
$ SET VERIFY
$ ON ERROR THEN GOTO EXIT
$ R [TURNER]WAVELS
-1
0
Y
N
N
N
M17360, DIR=30, S=6", 6 @ T=2.00 SEC
2.000
4
M17360
$ PRINT FOR001.DAT
$ PU FOR001.DAT
$ EXIT:
$ SET NOVERIFY
```

Table F1

Procedure for Program DISKDISK

Stage 1, Preprocessing Wave Analysis

Step	Description	Input	Comments
1	Log on User ID: Password:	 Hampton	 Get current password from Hampton
2	End of test	End	Sends message to users informing testing is completed
3	Preprocessing edit	EDD	Edits command file DISKDISK, input described in Steps 4 & 5, close file using standard procedure
4	Disk filename	M17360	
5	Run #	1	Enter appropriate run #
6	Run DISKDISK	RDD	Combines calibration coefficients from Process IDCAL w/data from Process TAPEM2 into diskfile specified in Step 4. Now in [DATA_ANAL] subdirectory

Table F2

Procedure for Program WVANSDISK1

Stage 2, Zero-Crossing Wave Analysis

Step	Description	Input	Comments
1	Log on		
	User ID:	Hampton	
	Password:		Get current password from Hampton
2	Change directory	SDA	Set default to [DATA_ANAL]. If run concurrently w/Stage 1, already in subdirectory, omit step
3	Zero-crossing edit	EWA	Edits command file WVANSDISK1. Input described in Steps 4-12
4	Analysis periods	-1	-1=All Enter # periods .LE. # collected & specified in Process IDCAL
5	Skip records	0	0=process all Enter # records to skip prior to processing
6	Limited output	Y	Y=Std output, N=Detailed output
7	Summary output	Y	Y=Std output, N=Detailed output
8	Process channels	Y	Y=All, skip Steps 8a-8b below N=Process selected channels only, see Steps 8a-8b
8a	How many	3	Enter # channels to process, .LE. total available
8b	Channel #'s	7 8 9	Enter channel #'s to process, one per line
9	Plot data	Y	Y=Yes, N=No plots desired, skip Steps 9a-9b
9a	x-axis length	7.	Enter length of x-axis in inches
9b	x-axis increment	2.	Enter x-axis increment in seconds
10	Descriptive title		Enter .LE. 40 characters
11	Depth	1.0	Feet, does not seem to make any difference

(Continued)

Table F2 (Concluded)

Step	Description	Input	Comments
12	Filename	M17360	Enter diskfile containing data, same as created in Stage 1
13	Run WVANSDISK1	RWA	Runs WVANSDISK1, zero-crossing average & significant wave periods & heights for model & prototype. Prints tabular lists & plots (if requested)

Table F3

Procedure for Program WAVELS

Stage 3, Harmonic Wave Analysis

Step	Description	Input	Comments
1	Log on		
	User ID:	Hampton	
	Password:		Get current password from Hampton
2	Change directory	SDA	Set default to [DATA_ANAL]
3	Harmonic analysis	EHA	Edits command file WAVELS. Input described in Steps 4-13
4	Analysis periods	-1	-1=All Enter # periods .LE. # collected & specified in Process IDCAL
5	Skip records	0	0=process all Enter # records to skip prior to processing
6	Process channels	Y	Y=All, skip Steps 6a-6b below N=Process selected channels only, see Steps 6a-6b
6a	How many	3	Enter # channels to process, .LE. total available
6b	Channel #'s	7 8 9	Enter channel #'s to process, one per line
7	Plot raw data	N	Y=Yes, N=No plots desired
8	Plot raw data & fit	N	Y=Plots of raw & least-squares fit data desired N=No plots desired
9	Plot residuals	N	Y=Plots of residuals desired N=No plots desired
10	Descriptive title		Enter .LE. 40 characters
11	Wave period	2.0	Fundamental period in seconds
12	# Components	4	Enter # of harmonics desired

(Continued)

Table F3 (Concluded)

Step	Description	Input	Comments
13	Disk filename	M17360	Enter diskfile containing data, same as created in Stage 1
14	Run WAVELS	RHA	Runs [TURNER]WAVELS harmonic analysis for percent variance in each harmonic. Prints tabular lists & plots (if requested)
15	Logoff	LO	

APPENDIX G: NOTATION

a_j	Real Fourier coefficients
A_j	Amplitude of j^{th} component
a_0	Fourier coefficient
A_o	Mean water surface elevation
B	Width of paddles of DSWG
b_j	Imaginary Fourier coefficients
C	Wave celerity or phase speed
C_g	Group velocity of wave
E	Variance of wave signal
f	Frequency, Hz
f(w)	Function of θ with w as a dummy variable
$F_2(f)$	Two-dimensional wave height transfer function
$F_3(f,\theta)$	Three-dimensional wave height transfer function
h	Water depth
H	Wave height
$\bar{H}$	Average wave height in measurement area
H_b	Maximum prebreaking wave height
H_n	Wave height measured at gage n
H_p	Wave height of the p^{th} spurious wave component
H/L	Wave steepness
H/S	Height-to-stroke ratio
$H(\theta)$	Wave height of main component wave; wave height corrected for directional effects
j	j^{th} component
J	Total number of components
k	Wave number
L	Linear, shallow-water wavelength

N	Total number of data samples
N_ℓ	Number of DSWG paddles required to make one cycle
p	Index for spurious wave components
S	Wavemaker stroke
$S_c(y,t)$	Control signal for linear sinusoidal waveforms
t	Time
T	Time for wave to travel between two points
T_{min}	Minimum period below which spurious waves will be generated
T_1	Travel time to back gage row located 30 ft from DSWG
T_2	Travel time to reflect off back wall and return to back gage row
w	Dummy variable of integration
X	Coordinate axis
Y	Distance along DSWG corresponding to one cycle; coordinate axis
$\Delta\bar{H}$	Mean wave height variation
ΔL	Incremental wavelength
Δt	Time interval
Δy	Distance between wave gages parallel to DSWG
$\xi(t)$	Paddle displacement time series
$\varepsilon(t)$	Noise component of water surface elevation time series
$\eta(t)$	Water surface elevation time series
$\eta_m(t)$	Measured water surface elevation time series
$\eta_t(t)$	True component water surface elevation time series
Θ	Wave direction, angle of wave propagation; angle between wave crest and DSWG
Θ_m	Measured wave direction
Θ_p	Direction of p^{th} spurious wave component
Π	Goda's nonlinear parameter

π 3.14159

ϕ Phase lag between paddles of DSWG

ϕ_j Phase of j^{th} component

ϕ_t Total phase lag for wave generation, consists of frequency increment, constant, and offset portions

ϕ_y Constant plus offset phase lag for wave generation

ω_j Angular frequency of j^{th} wave component